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UNITED STATES
DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
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INFORMATION CIRCULAR

ANNUAL REPORT OF RESEARCH AND TECHNOLOGIC WORK ON COAL

FISCAL YEAR 1938

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A. C. FIELDNER

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

ANNUAL REPORT OF RESEARCH AND TECHNOLOGIC WORK ON COAL, FISCAL YEAR 1938[1]

By Arno C. Fieldner[2]

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[2] Chief, Technologic Branch, and Chief Engineer, Coal Division, Bureau of Mines, Washington, D. C.

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FOREWORD

This report, the third of a series of annual reports of research and technologic work on coal by the Technologic Branch to be released in this form, covers the fiscal year July 1, 1937, to June 30, 1938.

Ever-increasing demands for information on the chemical and physical properties of coals, their proper classification and adaptability for various uses, their economic evaluation in the complex relationships between the costs of production, distribution, and selling, and their beneficiation and amenability to conversion to more valuable and new products of commerce have necessitated an appropriate and flexible program. To meet these requirements, initiation of new projects and new physical facilities has been made.

During the fiscal year a new field station at Golden, Colo., where the utilization of subbituminous coal and lignite will be studied, and a pilot plant at the University of North Dakota, Grand Forks, N. Dak., where the Fleissner process of drying lignite will be studied, were built in accordance with the Congressional act described in Senate bill 3743, 74th Congress, approved May 15, 1936. The experimental plant for the hydrogenation of coal at the Central Experiment Station, Pittsburgh, Pa., has been enlarged and additional equipment provided to facilitate this work. These new facilities are described in detail in this publication.

ACKNOWLEDGMENT

This report has been prepared from statements submitted by the supervising heads of all sections in the Coal Division and of certain sections in the Mining, Nonmetals, and Explosives Divisions, and from recent publications by members of these divisions. Special acknowledgments are made to the following members of the Technologic Branch staff:

Coal Division

J. F. Barkley, supervising engineer, fuel economy section,
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P. Nicholls, supervising engineer, fuels section,
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W. J. Huff, consulting explosives chemist, Eastern Experiment Station, College Park, Md.,
J. E. Tiffany, explosives testing engineer, Central Experiment Station, Pittsburgh, Pa.

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Colorado School of Mines, Golden, Colo.
Pennsylvania State College, State College, Pa.
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University of North Dakota, Grand Forks, N. Dak.
University of Washington, Seattle, Wash.

PROPERTIES AND COMPOSITION OF AMERICAN COALS

The research and technologic program for surveying the properties and composition of American coals has been steadily improved and enlarged since the creation of the Bureau of Mines in 1910.

Increasing demands for information on the suitability of American coals for various present and proposed uses, their classification, and the economics of production, distribution, and selling require detailed knowledge of their chemical and physical properties.

Fuel Inspection and Coal Analyses

During the fiscal year, 8,681 samples of coal, coke, and related products were analyzed in the coal-analysis laboratory. Of these, 6,646 were analyzed in connection with purchases of coal for the use of Government and certain State institutions and for classification of coals by the National Bituminous Coal Commission, 1,823 related to the research program of the Bureau, and 212 were miscellaneous samples submitted for checking purposes.

Two automobile trucks equipped for accurate and rapid preparation of coal samples were operated continuously for 10 months, beginning September 1937. Coal was inspected at 10 anthracite breakers, and 51 anthracite samples were collected in Pennsylvania and 18 tipple and 27 face samples at 7 mines in the Valley coal field in Virginia. These latter samples from the Brushy Mountain region, when analyzed, established this coal as semianthracite in rank.[3] Bituminous-coal collection included 574 tipple, 60 experimental moisture, and 9 drop shatter and screen samples representing 129, 14, and 9 mines in Pennsylvania; 94 tipple and 3 face samples at 21 mines in western Kentucky; 9 face, 2 carbonization, and 2 samples for microscopic examination at 3 mines in eastern Kentucky; and 3 face, 1 carbonization, and 1 sample for microscopic examination at 1 mine in West Virginia. In addition to these coals in the United States, the Alaska Railroad sampled and analyzed 480 coals purchased by them.

Technical Paper 590, Analyses of Pennsylvania Bituminous Coals, was prepared.[4] The methods employed in various countries for sampling and analyzing solid fuels were reviewed critically[5] preliminary to revisions of Technical Paper 76, Notes on the Sampling and Analysis of Coal[6], and Technical Paper 8, Methods of Analyzing Coal and Coke.[7] The revision of Technical Paper 76 was issued as Technical Paper 586 and describes the current practice in sampling and analyzing coal, the progress made in laboratory methods, and the bearing of the results on various problems connected with the efficient utilization of coal. The current revision of Technical Paper 8 includes improvements made in methods for the proximate and ultimate analysis of coal and coke, and, in addition, methods for determination of forms of sulphur in coal, carbon dioxide in coal, agglomerating index of coal, forms of iron in coal-ash slags and clinkers, and methods of analysis of coal and coke ashes.

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[3] American Society for Testing Materials, Standard Specifications for Classification of Coals by Rank (D 388-38; A.S.A. M 20.1 - 1938): 1938 Supplement to Book of Am. Soc. Test. Mat. Standards, September 1938, pp. 157-62; Am. Soc. Test. Mat. Standards on Coal and Coke (prepared by Committee D-5 on Coal and Coke), October 1938, pp. 104-111.

[4] Ashley, G. H., Toenges, A. L., Anderson, R. L., Rice, W. E., Stull, C. M., Snyder, N. H., Swingle, R. J., Cooper, H. M., and Abernethy, R. F., Analyses of Pennsylvania Bituminous Coals: Bureau of Mines Technical Paper 590 (in press).

[5] Fieldner, A. C., and Selvig, W. A., Review of Standard Methods Used in Various Countries for Sampling and Analysis of Solid Fuels: Fuel, vol. 17, 1938, pp. 266-271.

[6] Fieldner, A. C., and Selvig, W. A., Notes on the Sampling and Analysis of Coal: Bureau of Mines Tech. Paper 586, 1938, 48 pp.

[7] Stanton, F. M., Fieldner, A. C., and Selvig, W. A., Methods of Analyzing Coal and Coke: Bureau of Mines Tech. Paper 8, rev. ed., 1938.

A method for determining the forms of sulphur in hydrogenated coal residues was published.[8]

The importance of sampling and correct interpretation of a number of coals rather than dependence on a single sample was emphasized.[9] The need for differentiating between different kinds of moisture in coal, particularly for purposes of accurate coal classification, was discussed.[10] Studies on anthracite showed the relation of oxidation to change in composition and heating value.[11] Combined studies of laboratory analyses and operating results over a period of time are essential for an accurate evaluation of a heterogeneous material like coal, even when proper sampling procedures are followed.[12] It is believed that distribution curves are better criteria than frequency curves to characterize the occurrence of ash in a given coal.[13] Treatment of the basic principles underlying coal sampling as a statistical problem should be encouraged as a promising means of reducing field labor and coordinating different sampling methods.

The Bureau cooperated with the American Society for Testing Materials and the American Standards Association in developing recently adopted specifications and methods of test for coal and coke. These include standard specifications for classification of coals by rank[14] and by grade[15]; tentative methods of test of drop shatter[16], of tumbler[17], and for grindability of coal[18]; adoption of a tentative revision of a former standard as standard for laboratory sampling and analysis of coal and coke[19]; and standard methods of test for screen analysis of coal[20] and for designating size of coal from screen analysis[21].

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[8] Abernethy, R. F., Cooper, H. M., and Tarpley, E. C., Determination of Forms of Sulphur in Insoluble Residues from Hydrogenated Coal: Ind. and Eng. Chem., anal. ed., vol. 10, 1938, pp. 389-90.

[9] Fieldner, A. C., Discussion of "Interpretation of Laboratory Coal Tests - Proximate Analysis and Calorific Value", by G. B. Gould: Proc. Am. Soc. Test. Mat., vol. 37, pt. 2, 1937, p. 364.

[10] Yancey, H. F., Discussion of "Need for a Standard Method for Determining Surface Moisture in Coal", by T. W. Guy: Trans. Am. Inst. Min. and Met. Eng., Coal Div., vol. 130, 1938, p. 248.

[11] Scott, G. S., Jones, G. W., and Cooper, H. M., The Effect of Oxidation on the Volatile Matter of Anthracite and its Significance in Mine-Fire Investigations: Bureau of Mines Rept. of Investigations 3398, 1938, 6 pp.

Scott, G. S., Jones, G. W., and Cooper, H. M., The Oxidation of Anthracite and Its Relationship to the Decrease in Heating Value: To be published in Ind. and Eng. Chem.

[12] Barkley, J. F., Discussion of "Statistical Interprepation of Laboratory Coal Tests and Sampling Methods", by G. B. Gould: Trans. Am. Inst. Min. and Met. Eng., Coal Div., vol. 130, 1938, pp. 220-22.

[13] Landry, B. A., Discussion of "Statistical Interpretation of Laboratory Coal Tests and Sampling Methods", by G. B. Gould: Trans. Am. Inst. Min. and Met. Eng., Coal Div., vol. 130, 1938, pp. 222-23.

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[14] See footnote 3, page 5.

[15] American Society for Testing Materials, Standard Specifications for Classification of Coals by Grade (D 389-37; A.S.A. M 20.2 - 1937): 1937 Supplement to Book of Am. Soc. Test. Mat. Standards, Sept. 1937, pp. 151-2; Standards on Coal and Coke (prepared by Committee D-5 on Coal and Coke), October 1938, pp. 112-113.

[16] American Society for Testing Materials, Tentative Method of Drop Shatter Test for Coal (D 440-37T): Proc., vol. 37, pt. 1, 1937, pp. 820-6; Standards on Coal and Coke (prepared by Committee D-5 on Coal and Coke), October 1938, pp. 70-76.

[17] American Society for Testing Materials, Tentative Method of Tumbler Test for Coal (D 441-37T): Proc., vol. 37, pt. 1, 1937, pp. 827-31; Standards on Coal and Coke (prepared by Committee D-5 on Coal and Coke), October 1938, pp. 77-81.

[18] American Society for Testing Materials, Tentative Method of Test for Grindability of Coal by the Ball-Mill Method (D 408-37T): Proc., vol. 37, pt. 1, 1937, pp. 810-14; Standards on Coal and Coke (prepared by Committee D-5 on Coal and Coke), October 1938, pp. 60-64; Tentative Method of Test for Grindability of Coal by the Hardgrove-Machine Method (D-409-37T): Proc., vol. 37, pt. 1, 1937, pp. 815-19; Standards on Coal and Coke (prepared by Committee D-5 on Coal and Coke), October 1938, pp. 65-69.

[19] American Society for Testing Materials, Standard Methods of Laboratory Sampling and Analysis of Coal and Coke (D 271-37; A.S.A. M18-1937): 1937, Supplement to Book of Am. Soc. Test. Mat. Standards, Sept. 1937, pp. 153-93; Standards on Coal and Coke (prepared by Committee D-5 on Coal and Coke), October 1938, pp. 11-51. See also proposed revision in method of testing coal, pp. 152-54.

[20] American Society for Testing Materials, Standard Method of Test for Screen Analysis of Coal (D 410-38): 1938 Supplement to Book of Am. Soc. Test. Mat. Standards, Sept. 1938, pp. 163-65; Standards on Coal and Coke (prepared by Committee D-5 on Coal and Coke), October 1938, pp. 82-84.

[21] American Society for Testing Materials, Standard Method for Designating the Size of Coal from its Screen Analysis (D 431-38; A.S.A. M20.3-1938): 1938 Supplement to Book of Am. Soc. Test. Mat. Standards, Sept. 1938, pp. 166-68; Standards on Coal and Coke (prepared by Committee D-5 on Coal and Coke), October 1938, pp. 85-87.

Special Physical Testing of Coal

The friability[22], size composition[23], and grindability[24] of American coals have been subjects of special studies. The necessary equipment for both the Hardgrove and Yancey methods of determining coal grindability have been installed at the Central Experiment Station, Pittsburgh, Pa.

Origin and Constitution of Coal

Fundamental research on the origin and constitution of coal, as revealed by the microscope in the study of thin sections and polished surfaces, has been continued as a part of the survey of the gas-, coke-, and byproduct-making properties of American coals. Columnar sections were examined in detail from the top to the bottom of the Alma, Upper and Lower Cedar Grove, Dorothy, Eagle, and Beckley beds,[25] and of the Upper Banner and Indiana No. 4 beds[27]. The results of similar work covering the microscopic analyses of Upper and Lower Kittanning and Pond Creek beds have been put in manuscript form.

Through a cooperative agreement between the Bureau and Pennsylvania State College, the hydrogenation characteristics of the petrographic

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[22] Hertzog, E. S., and Cudworth, J. R., Friability of Alabama Coals: Bureau of Mines Rept. of Investigations 3384, 1938, 8 pp.

[23] Geer, M. R., and Yancey, H. F., Expression and Interpretation of the Size Composition of Coal: Am. Inst. Min. and Met. Eng., Coal Div., vol. 130, 1938, pp. 250-269.

[24] Hertzog, E. S., and Cudworth, J. R., Grindability of Alabama Coals: Bureau of Mines Rept. of Investigations 3382, 1938, 8 pp.
Yancey, H. F., and Geer, M. R., Ball-Mill Grindability Indexes of Some American Coals: Bureau of Mines Rept. of Investigations 3409, 1938, 9 pp.
Barkley, J. F., Discussion of "Pulverizer Performance as Affected by Grindability and Other Factors", by Martin Frisch and A. C. Foster: Proc. Am. Soc. Test. Mat., vol. 37, pt. 2, 1937, pp. 464-466.

[25] Fieldner, A. C., Davis, J. D., Selvig, W. A., Thiessen, R., Reynolds, D. A., Holmes, C. R., and Sprunk, G. C., Carbonizing Properties of West Virginia Coals and Blends of Coals from the Alma, Cedar Grove, Dorothy, Powellton, Eagle, Pocahontas, and Beckley Beds: Bureau of Mines Bull. 411, 1938, 162 pp.

[26] Fieldner, A. C., Davis, J. D., Thiessen, R., Selvig, W. A., Reynolds, D. A., Brewer, R. E., and Sprunk, G. C., Carbonizing Properties and Petrographic Composition of Upper Banner Bed Coal from Clinchfield No. 9 Mine, Dickenson County, Va., and of Indiana No. 4 Bed Coal from Saxton No. 1 Mine, Vigo County, Ind., and the Effect of Blending These Coals with Beckley Bed Coal: Bureau of Mines Tech. Paper 584, 1938, 81 pp.

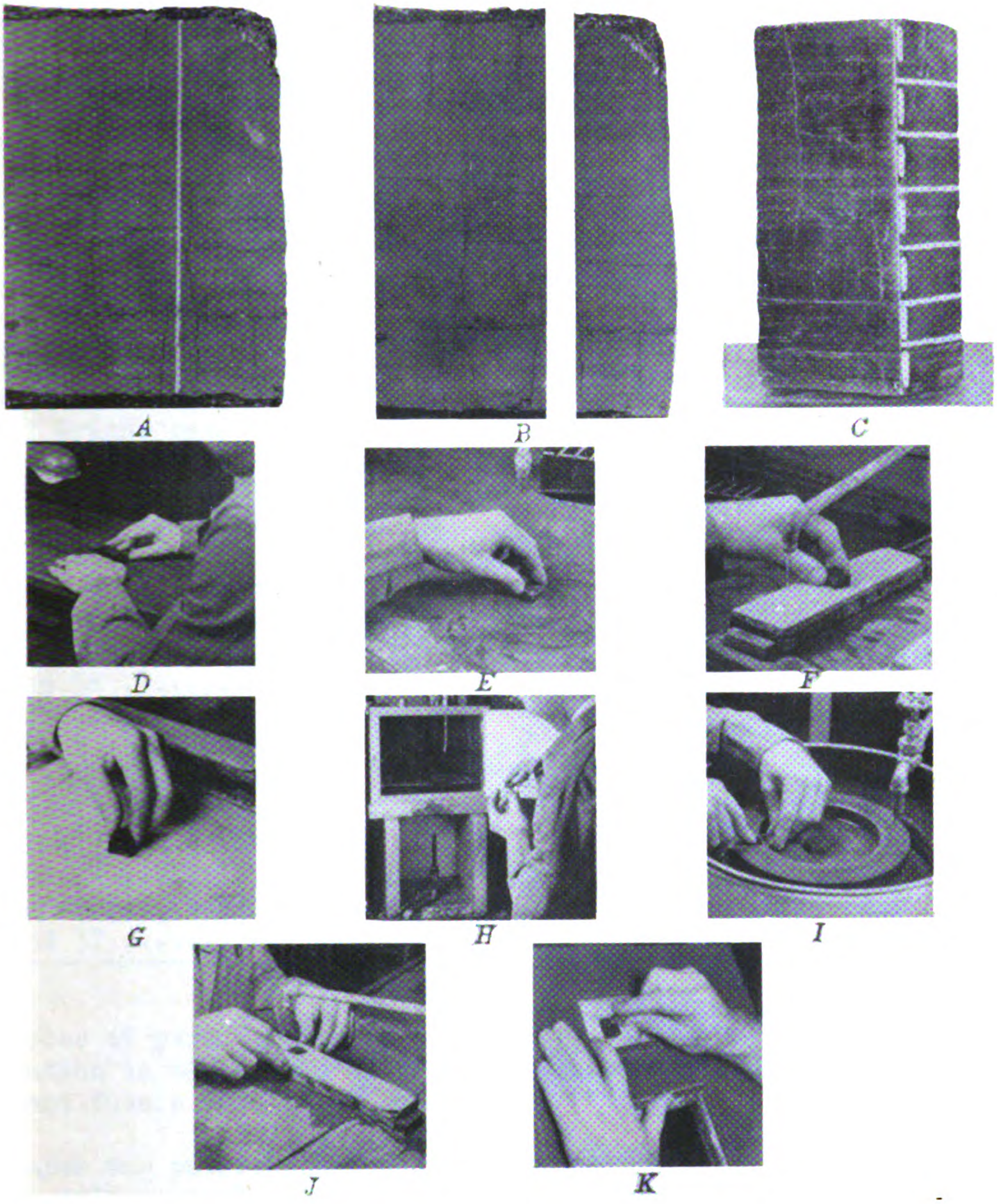

Figure 1.- Steps in preparation of coal for macroscopic and microscopic studies: A, First stage in polishing block of coal, butt-end surface of block sawed to proper dimensions (3 to 4 inches wide) and slice for thin sections cut perpendicular to butt surface through white line; B, slice, cut adjacent to block, used for making thin sections; C, manner in which exact position of thin sections is recorded on side of polished block; D, cube of coal cut for thin sections by means of a small Norton grinding wheel; E, method of grinding block to a plane surface; F, rubbing plane surface of block to a higher finish on a very fine-grained yellow Belgian hone; G, polishing block on a Selvyt cloth with slaked calcium oxide as polishing medium; H, cementing polished block to a glass object slide (it is absolutely necessary to have a thin even film of cement between specimen and object slide or succeeding operations will fail); I, grinding section as thin as possible on rim of a fine-grained 9-inch carborundum wheel; J, grinding thin section to proper thinness on a flat, fine-grained razor hone lubricated by a stream of water; K, final stage in preparing thin section (the section held against a lighted window is polished by using a softened cork dipped in a polishing powder).

components of two coal beds, Pittsburgh and High Splint, are being investigated. These beds were examined and classified by the Bureau, as shown in table 1. The samples were then sent to Pennsylvania State College for hydrogenation studies.

TABLE 1. - Petrographic composition of samples from Pittsburgh and High Splint bed coals

Sample	Anthraxylon	Translucent attritus	Opaque attritus	Fusain
Pittsburgh bed:				
Layer 1, bottom 49.1 inches of bright coal	71	18	8	3
Layer 2, top 13.9 inches, mixture (semisplint, splint, and bright)	38	33	27	2
Pure anthraxylon	100	0	0	0
Bright coal from sections 36 and 37	85	9.5	4	1.5
Semisplint, sections 57 and 58	37	30.5	30	2.5
High Splint bed:				
Layer 1, bright coal, bottom 6.4 inches	56	37	6	1
Splint from section 10	4	33	57	6
Splint from sections 23 and 24	3	35	60	2
Bright coal, sections 36 and 37	36	58	5	1

Samples of pure, or nearly pure, constituents have been isolated for hydrogenation in the Bureau's hydrogenation plant, and results on the constituent fusain were reported.[27]

A paper was published[28] describing the method of collecting representative column samples in the mine, the preparation from these, for macroscopic study, of relatively large polished blocks representing the entire column, and the preparation of thin sections of the column for microscopic analysis. The two latter procedures were described in detail. They are summarized photographically in figure 1.

During the past year new emphasis has been placed upon the correlation of physical and chemical properties through the additional evidence obtained

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[27] Fisher, C. H., Sprunk, G. C., Eisner, A., Clarke, L., and Storch, H. H., Hydrogenation of the Banded Constituents of Coal. Fusain: (To be published in Ind. and Eng. Chem.)

[28] Thiessen, R., Sprunk, G. C., and O'Donnell, H. J., Preparation of Thin Sections of Coal: Bureau of Mines Inf. Circ. 7021, 1938, 8 pp.; Fuel, vol. 17, 1938, pp. 307-15.

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from microscopical studies. One paper on the chemical and physical properties of spores from coal was published.[29] Similar studies on splint and cannel coals are being made.

The work on spores has shown them to be among the most conspicuous constituents in thin sections. In many coals they contribute considerable bulk. Pure spores are difficult to isolate in most coals, but in a Michigan high-ash spore coal they were found loosely embedded in the coal mass. Representative spores separated from this coal are shown in figure 2. The cleaned spores were analyzed, tested for agglutinating value, and their coke and byproducts yields determined by the Fischer low-temperature assay. These spores are characterized by a high hydrogen and volatile-matter content (7.6 and 76.6 percent, respectively, on a moisture- and ash-free basis). The carbonized residue was low, as would be expected from the low-ash and fixed-carbon contents of the spores. The yield of gas was slightly above normal and contained more hydrogen and less methane, whereas that of tar was exceptionally high (84.4 gallons per ton of spores) compared with like yields from other bituminous coals.

A paper describing the kinds of plants and which of their tissues and products contributed to the composition of coal was published.[30] The study shows (1) the major part of all coals, from peat to the Cretaceous bituminous coals, was formed from the remains of conifers, but (2) in the older Paleozoic coals the conifers, cycadophytes, and lycopods all took part in the formation. In the case of conifers, the xylem or wood, bark, and leaves were equally important contributors; the remains of cycadophytes included leaves, bark, and cortex, and the lycopods show the remains of wood, periderm, leaves, leaf bases, sporophylls, sporangia, and spores.

The angle of polarization as an index of coal rank promises to be an accurate and useful new criterion in coal-constitution studies.[31]

Standardization of Agglutinating-Value Test for Coal

Earlier work, which indicated that silicon carbide is superior to sand as the inert material in mixtures with coal to form test specimens before carbonizing, has been confirmed. Cooperative tests with another laboratory showed good agreement when the same coals were tested and different lots of silicon carbide were used. Rigid adherence to a definite procedure in preparing the silicon carbide-coal mixture is very important.

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[29] Sprunk, G. C., Selvig, W. A., and Ode, W. H., Chemical and Physical Properties of Spores from Coal: Fuel, vol. 17, 1938, pp. 196-99.

[30] Thiessen, R., Coal Paleobotany: Paper presented before the Paleobotanical Division of the American Association for the Advancement of Science, December 27 to 31, 1937, at Indianapolis, Ind.

[31] Thiessen, R., Discussion of "Angle of Polarization as an Index of Coal Rank" by L. C. McCabe and T. T. Quirke: Trans. Am. Inst. Min. and Met. Eng., Coal Div., vol. 130, 1938, pp. 454-455.

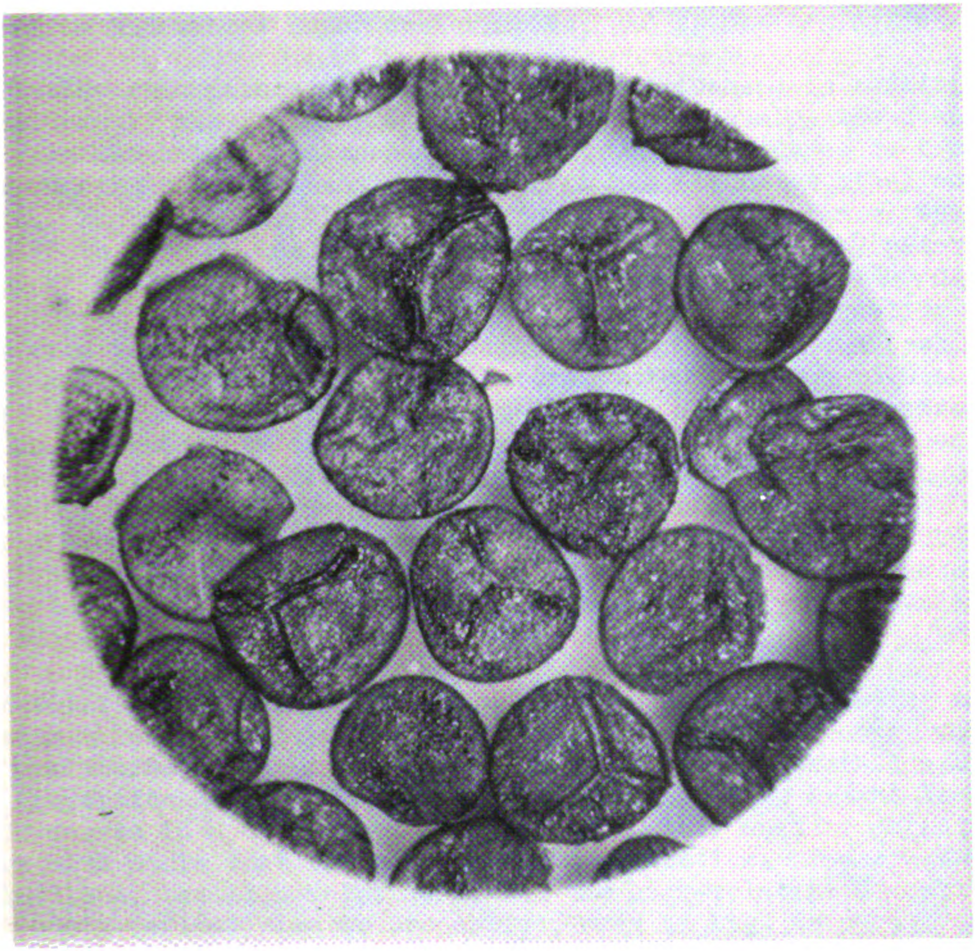

Figure 2.- Representative spores separated from Michigan spore coal by a method of crushing, washing, sieving, and subsequent flotation on calcium chloride solution.

Plasticity of Coal

During the fiscal year, tests of the plastic properties of all coals studied in the survey of the carbonizing properties of American coals have been made by the Agde-Damm dilatometer and Davis plastometer revised test methods.[32] Many additional tests by these methods have been made in connection with special studies on oxidized coals, low-volatile expanding coals, bright and splint layer coal samples, and spores segregated from coal.

Tentative conclusions show that very mild oxidation is sufficient to reduce considerably the fluidity of a coal. Simultaneously, the coking power of high-volatile bright coals on oxidation usually increases to a maximum and then decreases. For example, Pittsburgh bed (Bruceton mine) coal with an original high fluidity (less than 3 pound-inches resistance) temperature range (417° to 445° C., as measured in the Davis plastometer) after the addition of 19.5 grams of oxygen per kilogram of dry coal at 50° C. shows the same degree of fluidity over only 428° to 436° C. The quality of coke produced from this oxidized coal is improved and shows an increased stability factor (cumulative percent on 3/4-inch screen) from 57.8 to 68.0 and an increased hardness factor (cumulative percent on 4-mesh screen) from 67.2 to 76.7 as determined by tumbler tests. The friability of the coke under the same conditions is decreased from 55.5 to 51.9 percent. With continued oxidation (31.3 grams of oxygen added per kilogram of dry coal at 50° C.) the high fluidity disappears, the coke stability drops to 64.5, the hardness falls to 73.6, and the friability increases to 52.5 percent. These results show that for bright coals there is an optimum fluidity corresponding to coke of optimum quality.

Low-volatile bituminous coals are usually strongly expanding and produce strong, blocky cokes. Such coals, under normal test conditions in the Davis plastometer and Agde-Damm dilatometer, do not exhibit well-defined plastic properties under 500° C. When coked alone, they expand to a dangerous degree in a coke oven. Consequently, they must be coked in admixture with coals that become more fluid on heating. The lower-rank high-volatile A, the high-volatile B, and the high-volatile C coals also exhibit poorly defined plastic properties, even at high temperatures. These coals, however, usually produce weak cokes when coked in the normal way in an oven. The relationship between laboratory tests of the plastic properties of a coal and its behavior in a coke oven, particularly for the border-line coals that may be used alone, is being studied critically.

Samples of layers of bright coal develop moderate fluidity and high plastic resistance at the setting point of the plasticlike mass, whereas samples of layers of splint coal may become fluid but do not develop high resistance in the Davis plastometer. Bright coals generally expand in the laboratory dilatometer test, whereas splint coals show less expansion or are contracting over the usual plastic range of temperature.

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[32] Brewer, R. E., and Atkinson, R. G., Plasticity of Coals - Its Measurement and Relation to Quality of Coke Produced: Ind. and Eng. Chem., anal. ed., vol. 8, 1936, pp. 443-449.

Spores, picked out from coal, exhibit plastic properties only in slight degree; they distill, leaving only a small residue of crumbly coke.

The characteristics of coal plasticity developed under definite heating programs in the preplastic and plastic temperature range were discussed from the viewpoint of colloidal chemistry.[33]

During the year a new Davis plastometer was built with certain improvements that experience has indicated to be advisable. This apparatus is essentially like the older model[34], except that a flexible, direct-coupling drive and a suitable set of tension springs, which permit measurements of total resistances up to 130 pound-inches and a sensitivity of less than 0.2 pound-inch during the period of maximum fluidity, have been incorporated.

The Gieseler plastometer and test procedure[35] have been modified to permit satisfactory adaptations to the testing of American coals. The torsional principle used in the Davis plastometer is applied in a different manner in the Gieseler instrument. The coal charge in the Gieseler test is static at the start, and stirring begins only after the coal is softened initially by heating. The rate of stirring the charge, therefore, is proportioned to the fluidity of the coal mass. This permits particularly sensitive measurements over the fluid range, sharp distinctions to be made in the relative fluidities exhibited by different coals, and measurements of the low fluidity in coals bordering on the range of those cokes commercially without admixture. Figure 3 shows a line drawing of the modified Gieseler apparatus, and figure 4 gives a comparison of the plastic properties determined by the Gieseler and Davis plastometers on a high-volatile A coal. A paper presenting the details of construction of the modified Gieseler apparatus and test procedure together with a comparison of the results obtained with those on the same coals by the Agde-Damm dilatometer and Davis plastometer test methods was prepared.[36]

COAL MINING

The general scope of the Bureau's work dealing with coal mining was well-outlined in last year's report. The various sections in the Technologic and Health and Safety Branches contributing to this work have continued their studies on the problems then reported upon and also have initiated new investigations pertinent to current problems in coal mining.

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[33] Atkinson, R. G., Brewer, R. E., and Davis, J. D., Characteristics of Coal Plasticity: Ind. and Eng. Chem., vol. 29, 1937, pp. 840-844.

[34] Brewer, R. E., and Atkinson, R. G., work cited in footnote 33, p.

[35] Gieseler, K., Measurements of the Plastic Properties of Heated Coals: Glückauf, vol. 70, 1934, pp. 178-183.

[36] Brewer, R. E., and Triff, J. E., Measurement of Plastic Properties of Bituminous Coals. Comparison of Gieseler and Davis Plastometer and Agde-Damm Dilatometer Methods: To be published in Ind. and Eng. Chem., anal. ed.

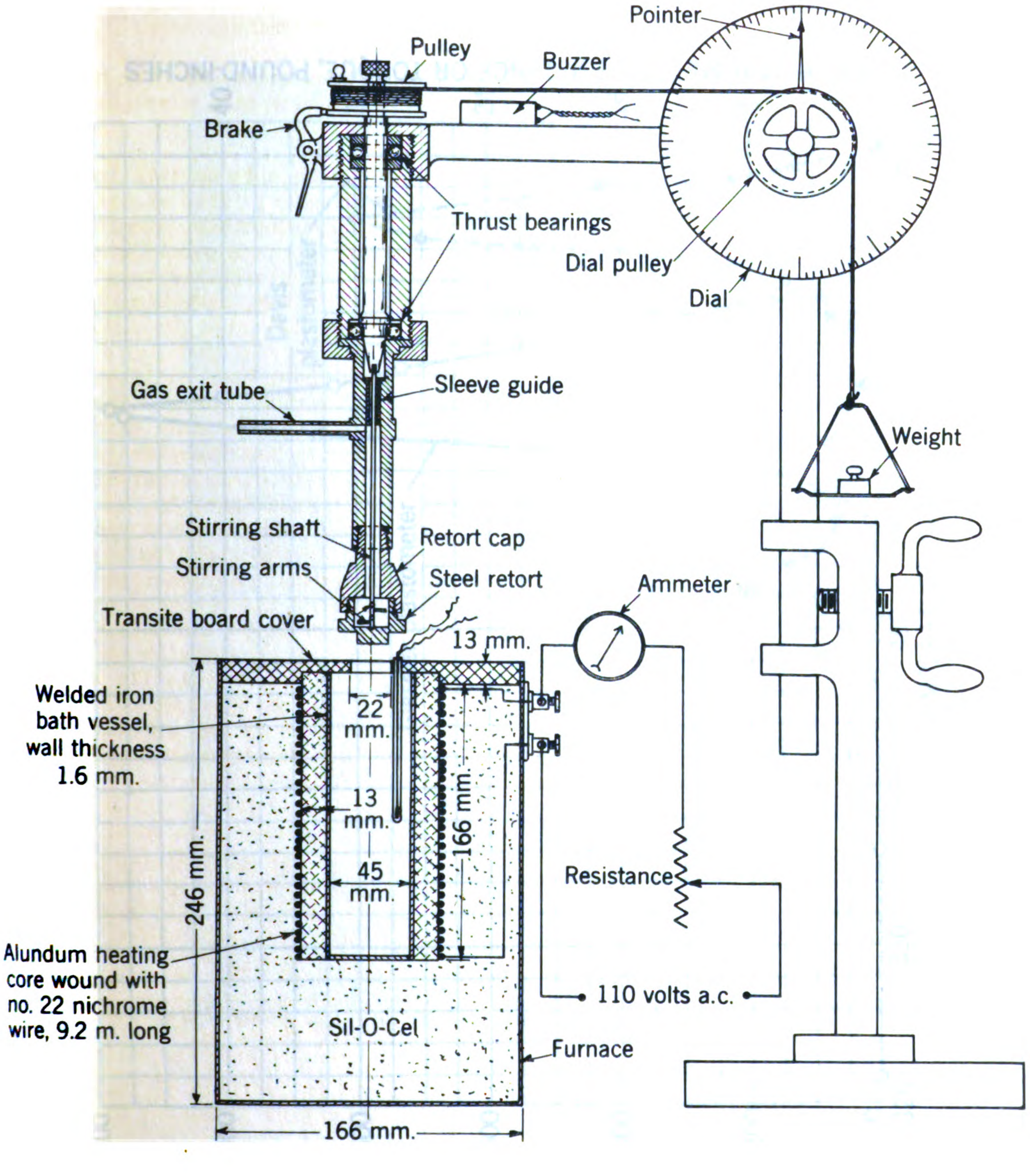

Figure 3.- Modified Gieseler plastometer apparatus.

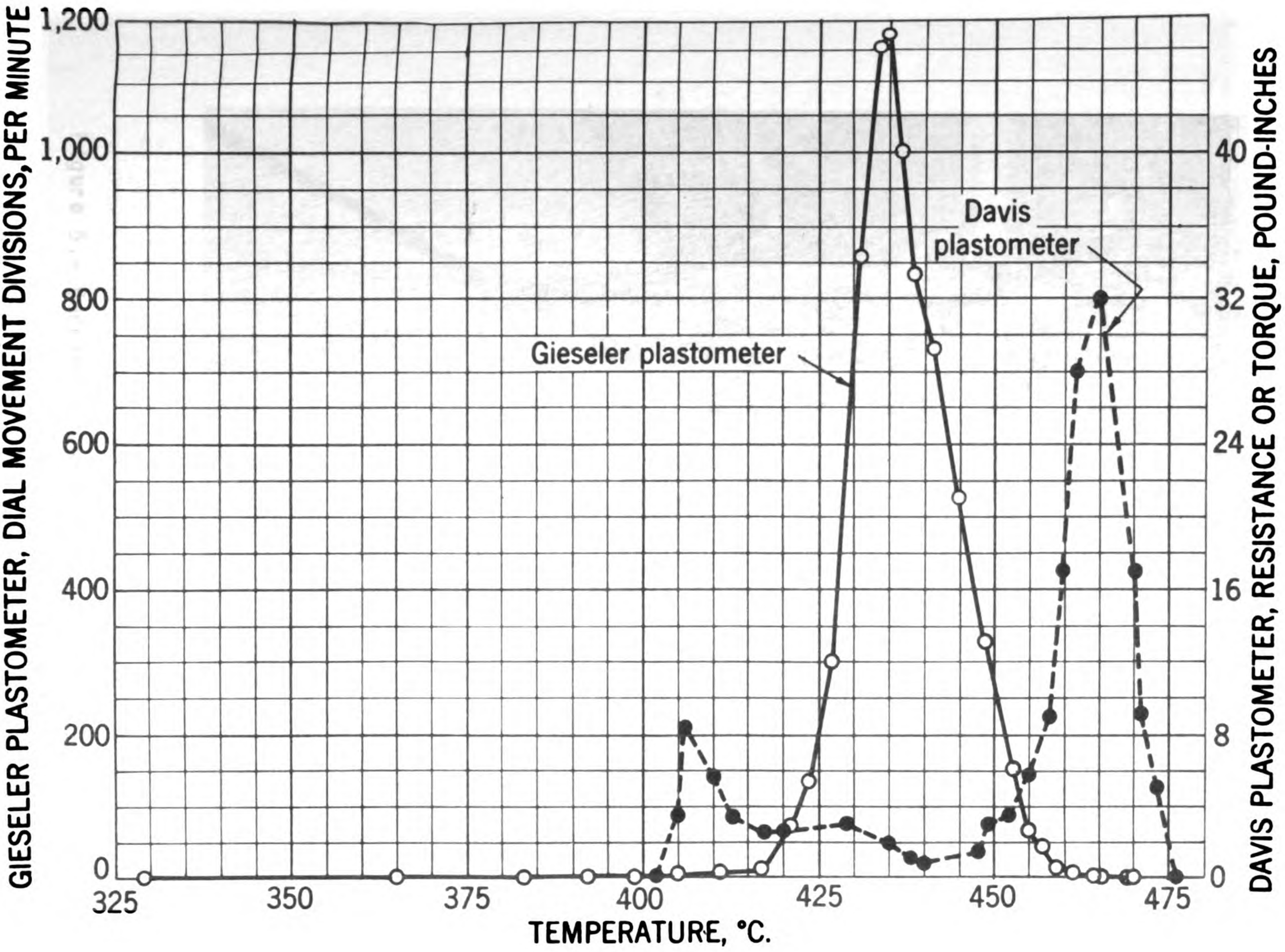

Figure 4.- Plastic properties of high-volatile coal.

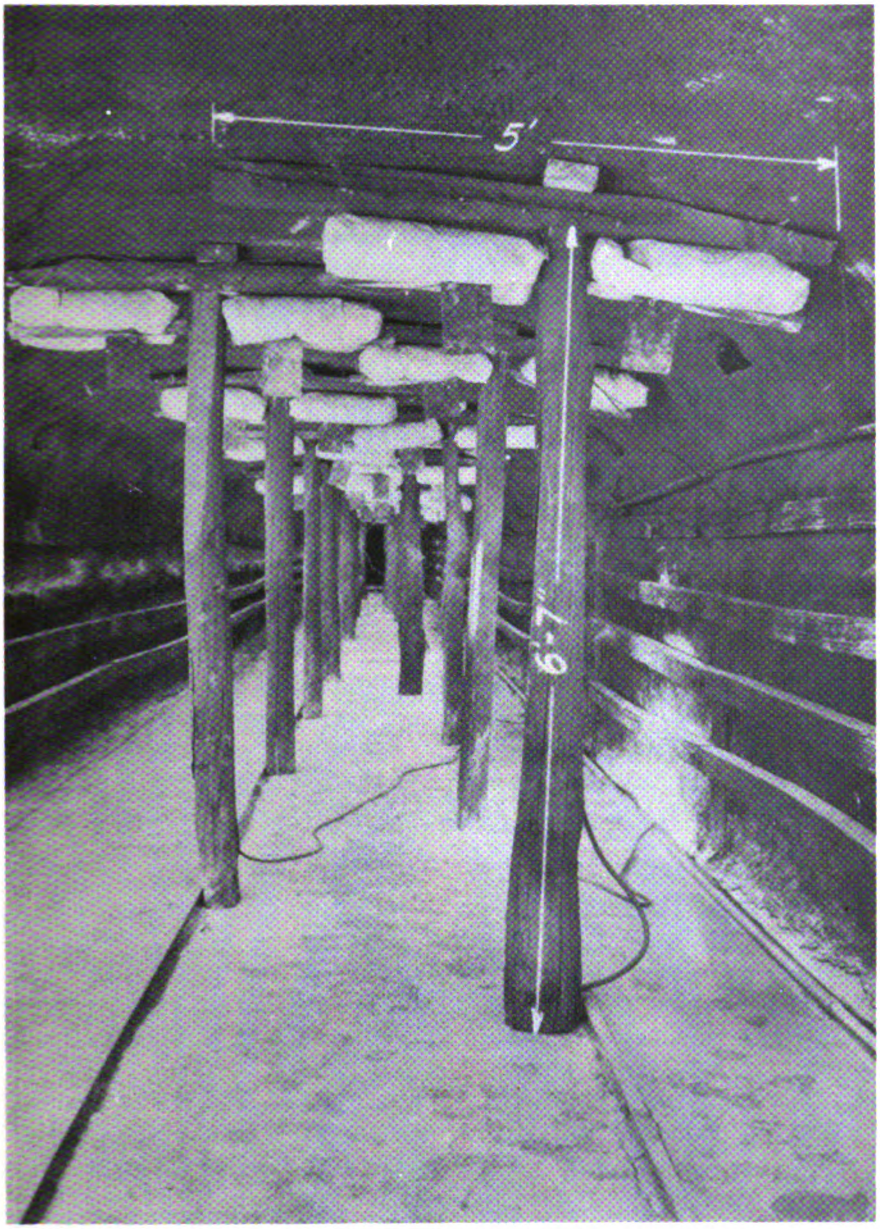

Figure 5.- Barrier using rock dust in bags installed for test.

Experimental Coal Mine

The three principal accomplishments during the year have been (1) tests to determine the efficacy of a novel type of rock-dust barrier designed by the safety director of a large coal corporation; (2) extension of studies of roof movement in coal mines and collection of data indicating that rapid movement of a rib line is favorable to good roof control; and (3) start of an investigation of the crushing strength of coal as it occurs in the ground.

Figure 5 is a photograph of the new-type rock-dust barrier installed for test in the experimental mine. Fifty-pound sacks of prepared rock dust rest on boards hinged to a post having an unusually long cap piece. The outer end of each board is supported by a vane and trigger arrangement, so that the filled sack is held tightly between board and cap piece. A rip wire, threaded through the top of each sack and fastened to the cap piece, completes the set-up. When an explosion occurs, the pressure waves operate the vanes, causing the boards to fall through an angle of about 45 degrees and pulling the rip wire through the top of the sack. The rock dust is thereby spilled in advance of the flame of the explosion. Tests on the barrier show that the dispersion of the dust, especially when the explosion is weak, is not as good as is desirable. Although this did not fail to stop flame movement in any of the tests made, better dispersion of the rock dust, if this could be effected in some cheap and practical manner, would be advantageous. In many respects this barrier[37] behaved similarly to others tested and reported previously.[38]

In connection with the barrier work, tests were made with a limestone dust so treated that each particle was coated with a water-repellent substance to keep the dust dry and free-flowing under conditions that render ordinary limestone dust useless. The treated dust showed only a slightly greater power to quench flame than did ordinary, dry, untreated dust of equal size.

A summary of recent trends in rock dusting covering the size, composition, caking quality, dispersibility, suitability (including health hazards), incombustibility of different rock-dust materials, methods of application, extent of practice, explosion-preventing qualities, effectiveness of maintenance, dust nuisance, and storage locations in mines was prepared.[39]

Five programs demonstrating the explosibility of coal dust were held during the fiscal year before 1,500 visitors. More than 300 other visitors were received at the Experimental mine during the year.

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[37] Greenwald, H. P., and Howarth, H. C., Tests of a Barrier Using Rock Dust in Paper Bags: Bureau of Mines Rept. of Investigations 3411, 1938, 16 pp.

[38] Rice, G. S., Greenwald, H. P., and Howarth, H. C., Tests of Rock-Dust Barriers in the Experimental Mine: Bureau of Mines Bull. 353, 1932, 81 pp.

[39] Greenwald, H. P., Recent Trends in Rock Dusting to Prevent Dust Explosions in Coal Mines: Am. Inst. Min. and Met. Eng., Tech. Pub. 975, 1938, 17 pp.

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The Coal and Safety Divisions cooperated in studies upon improvements in field demonstrations of the explosibility of coal dust, in safety-lamp tests, and in sound motion-picture production. A joint paper describing the mine rescue service of the Bureau was published in mimeographed form.[40]

Movement of Coal-Mine Roof

Results of completed studies of roof movement in Montour 10 mine were published.[41] The section studied is mechanized, and the retreating rib line moves rapidly. The immediate roof consists of a number of thin, weak beds of coal and slate having a total thickness of 10 feet or more. Above this is the hard, massive Pittsburgh limestone of variable composition. When mining operations are kept properly systematized, surface subsidence causes but little trouble, inasmuch as convergence of roof and floor is limited to the goaf and a relatively narrow zone along the ends of the retreating pillars. There is an important time factor in this convergence. Idle periods in which time effects can develop are unfavorable.[42]

A second mine presenting similar geologic conditions to those of the Montour mine, but in which hand loading is practiced and which has a slow-moving rib line, is under investigation. As a result of the slow movement and manner in which retreat work is conducted, convergence of roof and floor is greater than in the Montour 10 mine. Measurable subsidence of the surface occurs over unextracted coal and is preceded by a slight rise. Subsidence of the portion of the goaf adjacent to solid coal increases as the solid coal is removed. The results of studies of roof movement in this mine will be published shortly. A new phase of this investigation is the study of subsidence of a State Highway under which mining operations are now in progress, and the correlation of this subsidence with extraction of the coal. Data collected so far are insufficient to justify analysis. The physics of subsidence and ground movement in mines was discussed.[43]

The rapid extraction of pillars in relation to improvement of roof conditions and reduction of hazards depends upon other factors, such as the

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[40] Greenwald, H. P., and Forbes, J. J., Practical Experience for Mine-Rescue Corps Offered by the Bureau of Mines: 14th Safety Engineering Council, Pittsburgh, Pa., November 4-5, 1937. Mimeographed. (Not in Bureau series of mimeographed publications.)

[41] Greenwald, H. P., Maize, E. R., Hartmann, I., and Rice, G. S., Studies of Roof Movement in Coal Mines. 1. Montour 10 Mine of the Pittsburgh Coal Company: Bureau of Mines Rept. of Investigations 3355, 1937, 41 pp.

[42] Greenwald, H. P., Discussion of "Influence of Rate of Advance and of Time Factor in Support of Active Workings in Bituminous Coal Mines" by L. E. Young: Trans. Am. Inst. Min. and Met. Eng., Coal Div., vol. 130, 1938, p. 281.

[43] Greenwald, H. P., Further Notes on the Physics of Subsidence and Ground Movement in Mines: Jour. Appl. Phys., vol. 9, 1938, pp. 567-572.

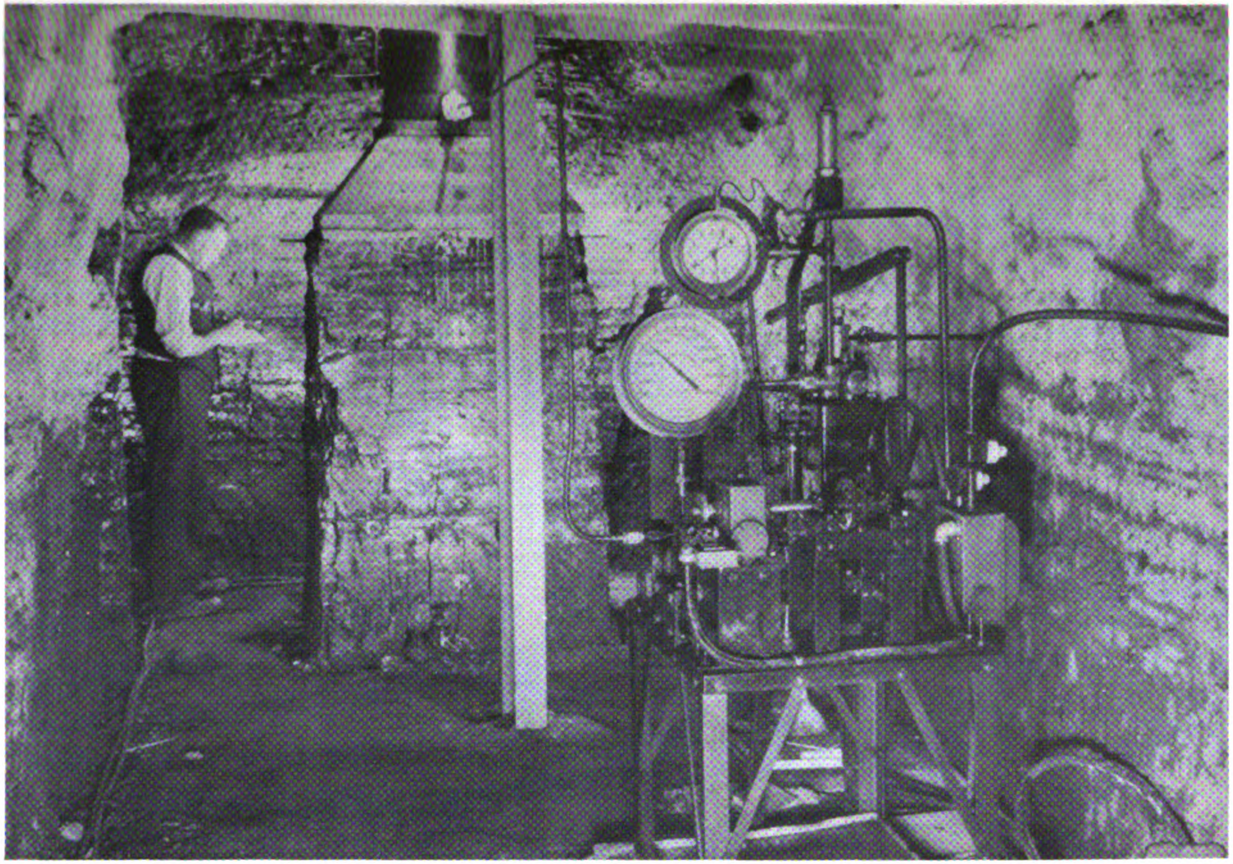

Figure 6.- Method of testing crushing strength of Pittsburgh coal bed vertically.

method of mining practiced and the synchronizing of operations for maintenance of proper rib lines.[44]

To measure the behavior of a whole pillar, observations should be made on its several faces.[45]

The measurements of pillar deformation in a bituminous-coal mine should be plotted against distance from the rib line, as well as against time, for accurate determination of the load on and, consequently, the compression of retreating pillars. The rib line may be considered as moving in proportion to the extraction of the coal. Simplification of test conditions and proper evaluation of observed data are necessary to reach reliable conclusions not otherwise obtainable.[46]

Compressibility and Crushing-Strength Tests in the Mine

The strength of pillars of coals left in mines, whether as barriers or to support the roof, has been the subject of widespread discussion and limited experiment for many years. Most engineers agree that crushing tests made in a laboratory outside of the mine do not have direct application to mine pillars, for two reasons: (1) If the specimen is large, it is damaged and its strength altered in the process of mining and transportation to the laboratory, and (2) if small, the effect of structure of the entire coal bed is lost. To investigate this problem under more favorable natural conditions it was decided to isolate and test the coal pillars in place. Consequently, the testing equipment had to be taken to the coal and test technique had to be developed. The first method of test is shown in figure 6. The coal pillar was isolated by excavating a narrow passageway around it, no explosives being used in the operation. Above the coal pillar is a truncated concrete pyramid, on which rests a hydraulic jack; the ram of this jack presses against the roof through a grillwork of steel designed to spread the load. The concrete pyramid distributes the load from the small base of the jack to the larger area of the coal pillar. A motor-driven pump with automatic controls maintains any desired constant pressure in the liquid system of the jack. Measurements of vertical compression and of lateral expansion of the pillar are made periodically during a test.

Tests on the first pillar showed that the fireclay floor underneath was weaker than the coal and was pushed outward from beneath the coal pillar. The lateral drag of the clay moving slowly by plastic flow was sufficient to pull the pillar apart from the bottom upward. Figure 6 shows unexpected failure along the vertical cleats of the coal. To avoid lateral flow of the fireclay, all clay surrounding the coal pillar was removed and replaced by concrete. The clay under the pillar was undisturbed. The test

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[44] Maize, E. R., To What Extent Does Rapid Extraction of Pillars Improve Roof Conditions and Tend to Reduce Hazards from Roof Falls?: Proc. Coal Min. Inst. America, 1937, pp. 94-95.

[45] Hartmann, I., Discussion of "Pillar Deformation in a Bituminous Coal Mine" by Charles T. Holland: Trans. Am. Inst. Min. and Met. Eng., Coal Div., vol. 130, 1938, pp. 351-352.

[46] Greenwald, H. P., Discussion of "Pillar Deformation in a Bituminous Coal Mine" by Charles T. Holland: Trans. Am. Inst. Min. and Met. Eng., Coal Div., vol. 130, 1938, pp. 352-353.

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then appeared as shown in figure 7. The vertical beams appearing on two sides of the coal pillar are used as fixed planes of reference for measurement of lateral movement of the sides of the pillar. The coal pillar was the height of the coal bed, approximately 5 feet and 4 inches, and was nearly square, with a cross-sectional area of about 1,000 square inches. It supported a load of 500 pounds per square inch for more than 48 hours and then failed suddenly, as shown in figure 8. Small movements leading up to the failure were revealed by the measurements during the 48-hour period. This work is being extended to pillars of greater cross-sectional area, approaching a cube in shape.

Tests of Inflammability of Dusts

Forty-one different samples, mostly from processing plants rather than from mines, were tested during the year. These samples included such materials as high-temperature and petroleum cokes, mixtures containing sulphur and aluminum, carbon black, fuel pitch, and a number of solid organic compounds processed from coal tar.

Physical Properties of Potash Salt

The use of potash-salt pillars as supports for roof-salt slabs during compression tests has been described.[47]

Coal-Mining Methods

Coal-mining practices in Europe are the subject of a comprehensive review.[48]

The advances in methods and practices of multiple-shift, mechanized mining of bituminous coal at 20 mines have been described.[49] Interesting facts brought out were the advantage of continuous flow of coal from face to tipple or central loading point; the necessity of adopting types of loading equipment and mining systems best suited to physical conditions; and the importance of constant supervision and regulation of all operations in the cycle of mining, such as working sites, labor, safety, and inspection and maintenance of mechanical equipment. Except for this latter operation, the third, or "graveyard", shift is considered inadvisable. The work is being extended to include other mines.

With improved designs of motor trucks and trailers, motorized haulage has been introduced successfully for short hauls in bituminous strip-mining operations in Ohio, Indiana, Illinois, Kentucky, Missouri, Kansas, and

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[47] Greenwald, H. P., and Howarth, H. C., Compression Tests of Roof-Salt Slabs Supported by Potash-Salt Pillars: Bureau of Mines Rept. of Investigations 3386, 1938, 16 pp.

[48] Rice, G. S., and Hartmann, Irving, Coal Mining in Europe: Bureau of Mines Bull. 414, (in press).

[49] Toenges, A. L., and Anderson, R. B., Multiple-Shift Mechanical Mining in Some Bituminous-Coal Mines. Progress Rept. 1: Bureau of Mines Inf. Circ. 7014, 1938, 56 pp.

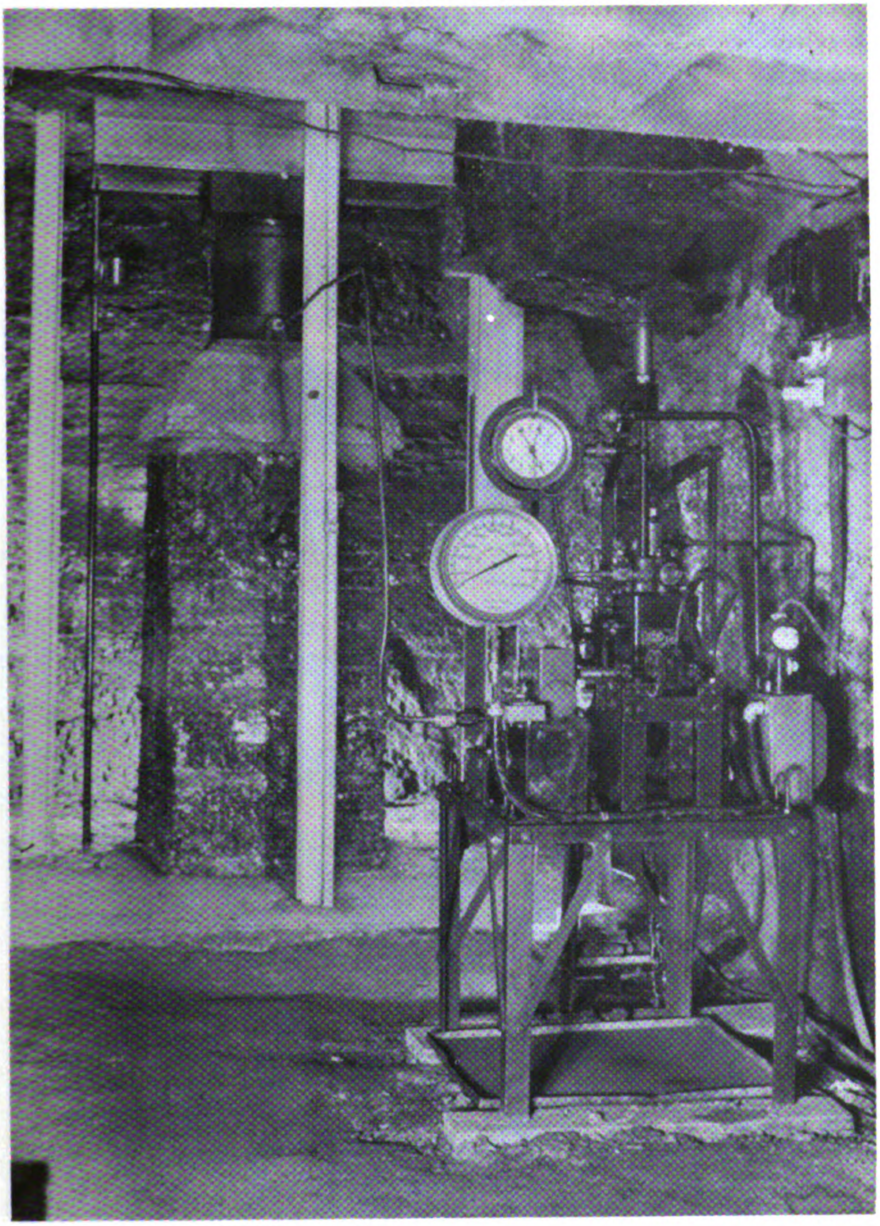

Figure 7.- Test of pillar with surrounding fire clay floor replaced by concrete.

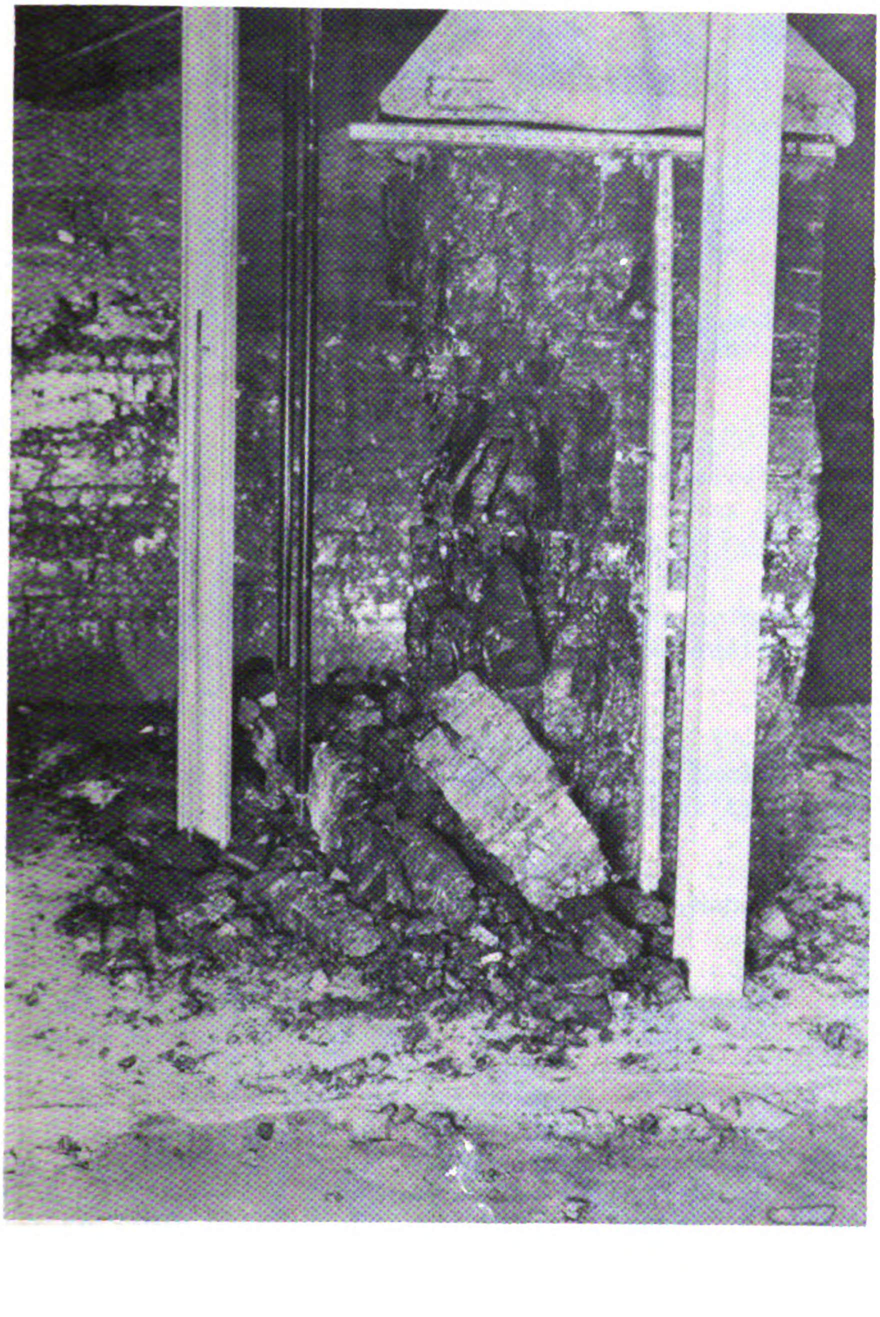

Figure 8.- Failure of pillar shown in figure 7.

Oklahoma. Motorized haulage has flexibility of operation and makes possible economical mining by shipping methods of isolated areas of coal and in rough country that could not otherwise be mined if large railway-haulage investments were first made. The trend toward larger-capacity motorized haulage equipment means, in some instances, increased investments in new private or public roads.[50] An extensive survey by the Bureau of both rail and motorized haulage in strip mines has been prepared.[51]

The use of mine bulkheads as a feasible method of preventing water from entering a working mine from adjoining closed mines was considered.[52]

A considerably more compressive material than sandstone to be used as the artificial roof strata to form immediate roof thickness has been suggested for tests by the barodynamic method in longwall mining operations.[53] The advisability of defining "squeeze" and summarizing and correlating such data as are known in reference to subsidence was also advocated.[54]

Ventilation

The subject of ventilation in coal mines has received continued study. A paper on ventilation practices in anthracite mines was published.[55]

Fires in Anthracite Mines

The problem of the cause, behavior, and control or extinction of fires in anthracite mines has been the subject of special studies.[56] Close cooperative work by personnel of the Mining, Health and Safety, and Explosives Divisions of the Bureau has been maintained so that all phases of this problem may be studied and correlated.

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[50] Toenges, A. L., Truck Haulage and Bituminous Coal-Strip Mining: Min. Cong. Jour., vol. 24, no. 9, September 1938, pp. 34-36.

[51] Toenges, A. L., and Jones, F. A., Truck vs. Rail Haulage in Bituminous Coal Strip Mines: Bureau of Mines Rept. of Investigations 3416, September 1938, 54 pp.

[52] Jackson, C. F., Discussion of "Bulkheads for Coal Mines" by John A. Garcia and Samuel M. Cassidy: Trans. Am. Inst. Min. and Met. Eng., Coal Div., vol. 130, 1938, p. 303.

[53] Greenwald, H. P., Discussion of "Effects of Immediate Roof Thickness in Longwall Mining as Determined by Barodynamic Experiments" by Phillip B. Bucky and R. V. Taborelli: Trans. Am. Inst. Min. and Met. Eng., Coal Div., vol. 130, 1938, pp. 330, 331.

[54] Greenwald, H. P., work cited in footnote 54, p. 331.

[55] McElroy, G. E., Ventilation at the Anthracite Collieries of the Northern Pennsylvania Field: Bureau of Mines Inf. Circ. 6965, 1937, 23 pp.

[56] McElroy, G. E., Some Observations on the Causes, Behavior, and Control of Fires in Steep-Pitch Anthracite Mines: Bureau of Mines Inf. Circ. 7025, 1938, 36 pp.
Scott, G. S., and Jones, G. W., The Composition and Inflammability of Gaseous Distillation Products from Heated Anthracite: Bureau of Mines Rept. of Investigations 3378, 1938, 6 pp.
Scott, G. S., and Jones, G. W., Oxidation of Anthracite: Effect of Time of Contact on the Concentration of Oxygen in the Effluent Gases: Bureau of Mines Rept. of Investigations 3405, 1938, 7 pp.
Jones, G. W., and Scott, G. S., The Role of Bacteria in the Elimination of Carbon Monoxide in Underground Atmospheres: (For publication in Ind. and Eng. Chem.)

Permissible Mine Equipment

Approval by the Bureau of electrically operated mine equipment and devices submitted by manufacturers is contingent upon compliance with minimum standards or requirements for safety as specified in Bureau publications known as "schedules." Formal approvals of 37 such devices and machines were issued during the fiscal year. These included 8 coal-cutting machines, 2 slate-cutting machines, 4 loading machines, 11 conveyors, 1 caterpillar truck, 1 room hoist, 1 mine pump, 1 rock-dust distributor, 1 hand lamp, 1 flashlight, 5 single-shot, dry-cell firing units, and 1 multiple-shot generator blasting unit of 10-shot capacity. The new types of equipment were (1) the multiple-shot generator blasting unit, the first approved under Schedule 16A;[57] (2) the self-propelled caterpillar truck for transporting mining machines or other equipment; and (3) two slate-cutting machines, each operated by a 100-horsepower motor. For many years a 50-horsepower motor was considered to be near the maximum rating that could be built for satisfactory operation with explosion-proof enclosures. The approved single-shot, dry-cell units, because of their low cost, should find increased use in promoting safety. Numerous changes in design in machines once approved were examined and, when found satisfactory, extensions of approval upon the revised machines were made.

Explosion-proof parts for incorporation in permissible machines frequently are made by firms other than those that market the assembled machine. These parts may be inspected and tested once for all by the Bureau and "letters of suitability" issued, which obviate the necessity for later approval. During the fiscal year, "letters of suitability" were issued for 11 DC and 6 AC motors, 2 DC and 2 AC current starters, 2 junction boxes, 2 headlights, 1 headlight resistor box, and 1 control station. Extensions were also issued to allow additional optional ratings and variations in construction.

The hazards of unguarded coal-cutting machines leading to permanent injuries and fatal accidents are receiving the cooperative attention of the Bureau, machine manufacturers and operators, mining companies, and certain State compensation and insurance agencies.[58]

Based upon a study of the properties of several commercial lamp fuels, tentative specifications for a satisfactory fuel for flame safety lamps were formulated.[59]

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[57] Bureau of Mines, Multiple-Shot Blasting Units: Requirements for Permissibility, Tests Made, and Fees Charged: Sched. 16A, 1937, 9 pp.

[58] Ilsley, L. C., Guarding the Bits of Coal-Cutting Machines: Proc. Coal Min. Inst. America, 1937, pp. 1-4.

[59] Hooker, A. B., and Coggeshall, E. J., Fuel for Permissible Flame Safety Lamps: Bureau of Mines Rept. of Investigations 3389, 1938, 5 pp.

Other publications on recommended mine equipment and materials and safety regulations governing their use in the mine were issued.[60]

Permissible Explosives and Blasting Devices

The permissible explosives recommended for use in coal mines, including their characteristics, selection, and safe use, have been described.[61] At present such explosives total 35 percent of all explosives used in coal mining, an increase of 31 percent over the relative percentage used 30 years ago. A list of permissible explosives and blasting devices approved by the Bureau was published recently.[62]

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[60] Ilsley, L. C., List of Permissible Mine Equipment Approved during 1937: Bureau of Mines Inf. Circ. 7007, 1938, 4 pp.
Ilsley, L. C., Gleim, E. J., and Brunot, H. B., Permissible Electrically Operated Hand-Held Coal Drills: Bureau of Mines Rept. of Investigations 3363, 1937, 13 pp.
Ilsley, L. C., Gleim, E. J., and Brunot, H. B., Permissible Electrically Operated Post Drills and Drilling Machines: Bureau of Mines Rept. of Investigations 3391, 1938, 17 pp.
Ilsley, L. C., and Gleim, E. J., State Regulations Pertaining to Hoisting of Men: (For publication as Information Circular.)
Schedule 10C, Electric Mine Lamps, Other Than Cap Lamps: Prepared by Electrical-Mechanical Section: Schedule 10C. July 1938, 8 pp.
Hooker, A. B., and Owings, C. W., Lighting Practices in Coal Mines of the United States: Bureau of Mines Inf. Circ. 7035, 1938, 11 pp.
Ilsley, L. C., and Hooker, A. B., Permissible Methane Detectors: Bureau of Mines Rept. of Investigations 3359, 1937, 4 pp.
Ilsley, L. C., and Gleim, E. J., State Regulations Pertaining to the Use of Internal Combustion Engines in Coal and Metal Mines and in Tunnels: Bureau of Mines Inf. Circ. 7019, 1938, 8 pp.
Gleim, E. J., Coal-Mine Fires of Electrical Origin: Their Cause and Prevention: Bureau of Mines Inf. Circ. 6981, 1937, 17 pp.
Ilsley, L. C., Fatal and Nonfatal Electrical Accidents in Coal Mines: Bureau of Mines Inf. Circ. 7011, 1938, 7 pp.

[61] Tiffany, J. E., Coal-Mine Explosives: Their Characteristics, Selection, and Safe Use: Proc. Coal Min. Inst. America, 1937, pp. 35-56.

[62] Active List of Permissible Explosives and Blasting Devices Approved Prior to June 30, 1937: Bureau of Mines Rept. of Investigations 3361, 1937, 22 pp. (No author, prepared by J. E. Tiffany.)

PREPARATION OF COAL

Coal Washing in Alabama

The Southern (Tuscaloosa, Ala.) Experiment Station, in cooperation with coal operators, has continued the studies on the washability characteristics of the most important Alabama coal beds and the performance of typical washing plants. A paper reviewing earlier work and devoting special attention to mechanical cleaning by jigs and wet-washing tables was published recently.63/ Charts are given showing the advantage of using the 0.10 specific gravity-distribution curve in determining the lowest specific gravity at which an efficient separation can be made between washed coal and refuse. As yet, no way has been devised to effect sulphur elimination beyond that which results from treatment in jigs and on tables during the regular cleaning process. Improvement in this respect would be desirable for some Alabama coking coals. The washing of coal usually decreases the clinkering trouble by reducing the volume of ash, although the ash-fusion temperature of the washed coal in some cases is no higher than for the unwashed.

Dewatering and Drying of Washed Coal

A compendium of information, including 65 bibliographic references on dewatering and drying of washed coal, was published.64/ The paper discusses the advantages and frequent necessity of dewatering and drying coal for certain purposes, the classification of moisture according to manner of retention in coal, methods and equipment used for dewatering and heat-drying, costs, and increasing practice in this country. Three illustrative examples of American dewatering and drying practices are described.

Coal Washing in the Pacific Northwest

An investigation of the efficiency of the separation made by means of two pulsator-type, coal-washing jigs on a sized feed of coal and impurities was completed by the Northwest Experiment Station in cooperation with the College of Mines, University of Washington.65/ One jig treated raw 3- to 1-1/4-inch (round-hole screen) egg coal; the other treated raw 1-1/4 to 1/4-inch nut coal. The major influence of specific gravity and the modifying influence of size of particle - here minimized by the use of a sized feed in a single unit - were evaluated by separating the feed, washed coal, and refuse from each jig into two size fractions and making complete specific-gravity analyses of each fraction.

63/ Gandrud, B. W., Coal Preparation in Alabama: 1937 Yearbook on Coal-Mine Mechanization, published by American Mining Congress, Washington, D. C., pp. 252-257.

64/ Cudworth, J. R., and Hertzog, E. S., The Dewatering and Drying of Coal: Bureau of Mines Inf. Circ. 7009, 1938, 31 pp.

65/ Yancey, H. F., Geer, M. R., and Shinkoskey, R. E., Performance of Pulsator-Type Jig: Bureau of Mines Rept. of Investigations 3372, 1938, 19 pp.

With respect to size, the egg-coal jig performed more efficiently on the finer portion, between 2 and 1-1/4 inches, whereas the efficiency of the nut-coal jig was about the same for the coarse and fine (1-1/4- to 1/2- and 1/2- to 1/4-inch) materials. The over-all efficiency for the feed as a whole in the egg-coal jig was 94 percent; that is, the washed coal contained 94 percent of the material of the feed and had an ash content of 11.9 percent. Corresponding values for the nut-coal jig were 99.6 and 12.1 percent.

The specific gravities of separation at which material in the raw coal was distributed equally between washed coal and refuse were 1.45 in the egg-coal jig and 1.69 in the nut-coal jig. The degree to which the jigs were able to separate their feeds into two products at these specific gravities is a measure of their effectiveness. With the egg-coal jig, 8 percent of the total feed reported to an improper product, and with the nut-coal jig this material represented 2 percent of the feed.

Separation of the raw coal and the resulting washed coal and refuse into five specific-gravity fractions by means of zinc chloride solutions made it possible to determine the proportions in which each specific-gravity component of the feed was divided between washed coal and refuse. Under the conditions of these particular washing operations, the very light or very heavy particles appeared in the proper product - washed coal or refuse, respectively - but as the specific gravity of particles in the feed approached that at which the separation was made, 1.45 or 1.69, the distribution to washed coal or to refuse became less sharp. Size of particle modified the effect of specific gravity in each specific-gravity fraction; in the egg-coal jig the proportion reporting to refuse was always larger in the coarser than in the finer size, and in the nut-coal jig considerable of the highest specific-gravity (1.80) fraction was not removed from the washed coal.

Comparison of the amount of material within the limits of ±0.1 of the specific gravities of separation for the two jigs showed that the higher efficiency in the nut-coal jig was due to the higher specific gravity at which the separation was made. Based upon the percentage distribution of material in the two jigs, this higher efficiency obtained with the nut-coal jig was shown to be due to the relative ease of separation rather than to better performance of the jig.

Clarification of Coal Washery Water

Experimental work upon the recovery of fine coal and impurities in the circulating water for cleaning coal showed that the capacity of settling tanks ordinarily used for recovering both the solids and the water could be increased substantially by the use of extremely small quantities of flocculating agents, such as wheat or corn flour.

UTILIZATION OF COAL

The coal-research program of the Bureau and the part it is serving in connection with the work and problems of other coal-research agencies, producers, and consumers in a coordinated whole, both in increasing the efficiency of utilization of coal and in promoting safety, was outlined.[66] The outstanding recent achievements in coal research and technology by the Bureau staff and others were summarized briefly.[67]

Extensive contributions were made during the year on the factors to be considered in the selection of coal for specific purposes. These papers were prepared in a series of numbered mimeographed articles[68] at the request of the National Committee on Coal of the National Association of Purchasing Agents. The material presented in certain of these articles has also been published elsewhere in more condensed form.[69]

Fuel Economy Service

Upon request, this service advises Government agencies on the purchase of fuel and equipment for Government heating and power plants. Acceptance tests of new equipment and operating tests for increasing fuel economy are conducted by the engineers of this section.

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[66] Fieldner, A. C., The Bureau of Mines and Coal Research: Proc., 19th Fuel Engineers' Meeting, Appalachian Coals, Inc., May 19, 1937, 7 pp. (mimeographed).

[67] Fieldner, A. C., and Rice, W. E., Advances in Coal Research and Technology: Min. Cong. Jour., vol. 24, no. 2, February 1938, pp. 50-52.

[68] Series of articles mimeographed by National Association of Purchasing Agents, New York, N. Y., to expand upon information contained in chart form in Pamphlet 21, Factors Recommended for Consideration in the Selection of Coal:

A Fieldner, A.C., Classification of Coal: Article 1, May 5, 1937, 7 pp.
B Barkley, J. F., The Specific Chemical Properties of Coal as Sampled: Article 2, June 8, 1937, 6 pp.
C ________ The Spreader Stoker: Article 4, June 22, 1937, 3 pp.
D ________ The Hand-Fired Down-Draft Furnace: Article 5, June 22, 1937, 4 pp.
E Rice, W. E., Factors in the Selection of Coal to be Used for the Firing of Ceramic Products (Use No. 10): Article 6, June 29, 1937, 6 pp.
F Selvig, W. A., Specific Physical Properties of Coal as Samples (Other Than Specific Volatile Index). Caking Properties of Coal Coke Button, Agglutinating Index, and Swelling: Article 16, November 30, 1937, 5
G ________ Specific Gravity of Coal. Specific Gravity of Lump and Bulk Density: Article 17, Dec. 7, 1937, 4 pp.
H Brewer, R. E., Specific Physical Properties of Coal as Sampled (Other than Specific Volatile Index). Plasticity of Coal: Article 20, Jan. 13, 1938, 7 pp.
I Yancey, H. F., The General Characteristics of Coal: Article 23, May 6, 1938, 5 pp.

[69] Rice, W. E., What Properties of Coal to Consider for Clay-Plant Kilns: Brick and Clay Record, vol. 92, no. 5, May 1938, pp. 13-15.

Savings to the Government of approximately $80,000 were made as a result of careful analyses of requested appropriations for new plants and proposed improvements in present installations, studies of comparative fuel costs, selection of more suitable fuels, and introduction of improved methods of handling and firing.

Such studies were made for the Bureau of the Budget, Veterans' Administration, Department of Agriculture, Department of Justice, and Office of Indian Affairs in 28 various locations in the United States and Alaska, and for the District of Columbia Government in 13 of its local power, heating, and incinerator plants.

Boiler feedwater-conditioning service has been applied to 878 samples of water for local plants in Washington and eight Government Departments. Tests of deaerating equipment were made at three power plants. New water-analysis laboratories have been established at the Capitol power plant and Howard University, and plans and specifications were prepared for a similar laboratory at the Eastern Experiment Station. The waters used at four plants near Boston were inspected and analyzed.

Consulting service has been provided for many Government agencies, particularly on the purchase of chemicals for boiler feedwater-conditioning and corrosion problems; on the analyses of bids and recommendations of awards for purchase of fuels; and, for and with the cooperation of other agencies, on the preparation of specifications for fuel oil, coal, coal storage and sizing, and contractional relationships in the purchase of coal.

Smoke-Abatement and Fly-Ash Control

Certain writings of the late O. P. Hood, formerly chief engineer, Mechanical Division, and chief, Technologic Branch, Bureau of Mines, on the subject of smoke abatement have been assembled in condensed form in a recent publication.70/ Restrictions on the emission of smoke, sulphur fumes, and fly ash have necessitated provisions for the control of these factors in coal-burning equipment.71/ In this connection, the profitable utilization of products recoverable from the flue gases, to pay for their removal, has attracted attention.72/

If it is assumed that all smoke particles have the same size and specific weight, the computation of smoke density in terms of light absorption may be expressed by the relation log (L_0 / L), where L_0 is the

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70/ Barkley, J. F., Smoke Abatement - Selections from Papers by O. P. Hood: Bureau of Mines Inf. Circ. 7016, 1938, 23 pp.

71/ Barkley, J. F., Smoke and Fly Ash from Spreader Stokers: Combustion, vol. 9, no. 12, June 1938, pp. 37-38.

72/ Barkley, J. F., Smoke and Fly-Ash Prevention at the Federal Central Heating Plant, Washington, D.C.: Proc. 31st Annual Conv., Smoke Prevention Association, 1937, pp. 120-128; 1937 Manual of Smoke and Boiler Ordinances and Requirements, Smoke Prevention Association, pp. 124-127.
Barkley, J. F., Fly-Ash Data from the Federal Central Heating Plant: Combustion, vol. 9, no. 6, December 1937, pp. 32-33.

intensity of light with no smoke and L with smoke. This expression, when multiplied by 12/B, where B is the length in inches of the column of smoke used in the test, permits construction of universal charts in terms of a 1-foot standard column.

Fuel-Savers Investigation

The effects on their combustion characteristics of pretreating coal and coke with small amounts of inorganic materials, described in last year's report, has continued to interest combustion engineers.[73] More complete treatments of this subject have been published.[74]

The utilization of waste heat from municipal incinerators in its economic relationship to necessary adjustments in other operating problems to effect this utilization is considered uneconomical at present relative prices of equipment, labor, fuel, and electricity at most incinerators.[75]

Studies of Slag-Forming and Ash-Fusion Properties

The effect of variation in percentage of ferric iron in a coal ash slag on its flow temperature shows that these factors are nearly linear functions of each other. Exceptions are noted (1) for high equivalent ferric oxide slags (above 35 percent) where the rate of increase of flow temperature decreases as the ferric percentage approaches that for slag melted in air, and (2) for all extremely low ferric percentages. In general, as the percentage is decreased below 5 percent, a sudden increase in flow temperature may be expected, although this critical zone may not be readily observable with all slags. Figure 9 shows the summarized data.

The "feel" method used in the first work for determining the degree of fluidity of molten slags is adequate for acquiring control data on slag-type furnaces and is necessary to obtain some information on a wide range of slags in a short time. However, it is not possible to determine fluidity by this method at temperatures above the flow temperature. It is important to know more precisely how fluidity changes above and below the flow temperature and to have a suitable method for determining temperature-viscosity data on coal-ash slags. The nature of the clinker formed in fuel beds at high rates of burning depends on the fluidity of the slag at high temperatures.

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[73] Nicholls, P., Reactivity and Chemical Treatment of Coals: Proc., 23d Fuel Eng. Conf., Appalachian Coals, Inc., May 5, 1938, 10 pp. (mimeographed); discussion 3 pp.

[74] Nicholls, P., Rice, W. E., Landry, B. A., and Reid, W. T., Burning of Coal and Coke Treated with Small Quantities of Chemicals: Bureau of Mines Bull. 404, 1937, 158 pp.
Nicholls, P., Chemical Treatment of Coal and Coke: Coal Heat, vol. 32, no. 6, December 1937, pp. 8-11; Am. Inst. Min. and Met. Eng., Coal Div., vol. 130, 1938, pp. 371-382; discussion pp. 382-387.

[75] Barkley, J. F., Discussion of "Incinerators Municipal, Industrial and Domestic" by H. S. Hersey: Trans. Am. Soc. Mech. Eng., vol. 60, 1938, pp. 284-285.

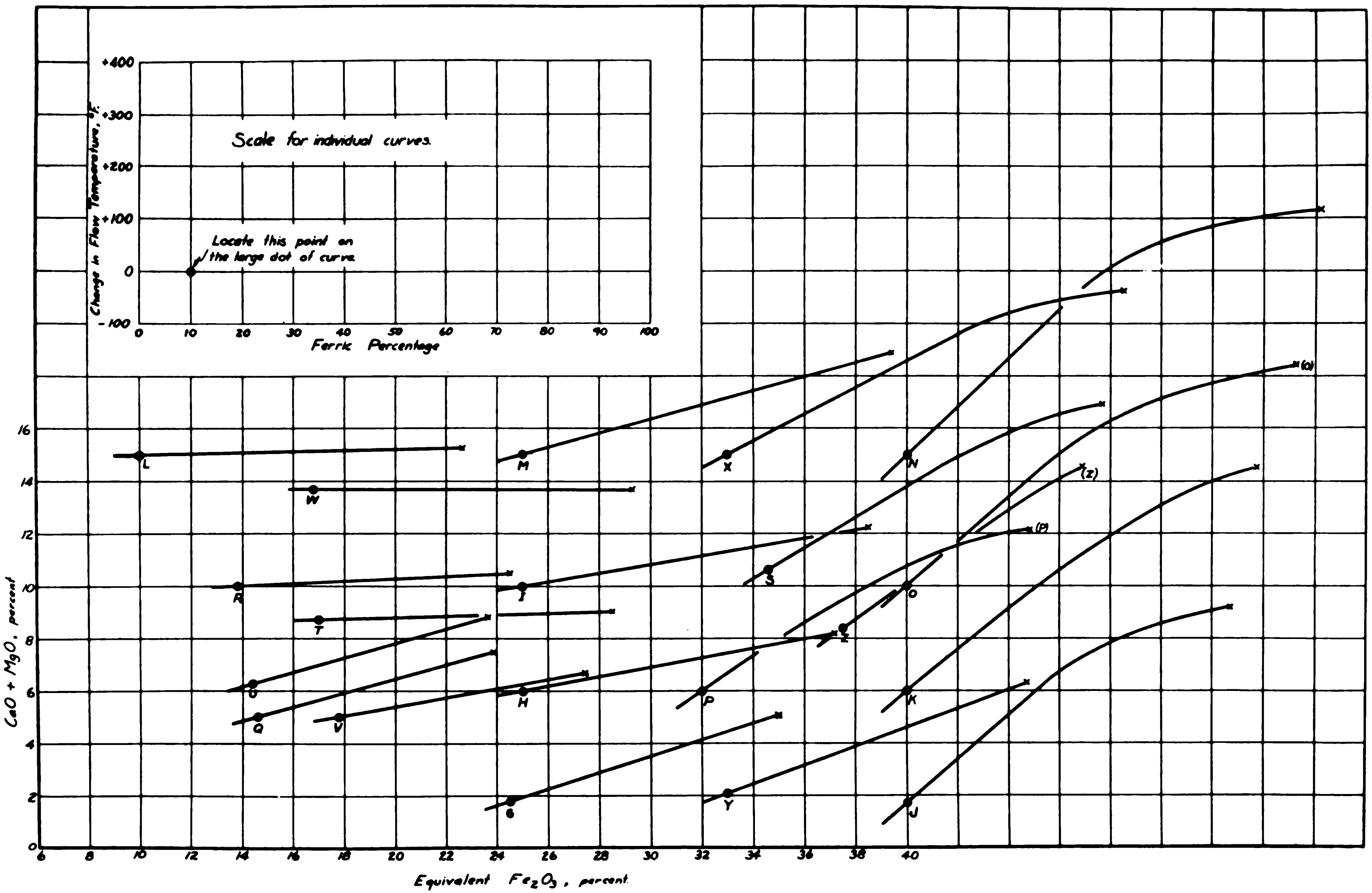

Figure 9.- Effect of ferric oxide percentage on flow temperature of coal-ash slags.

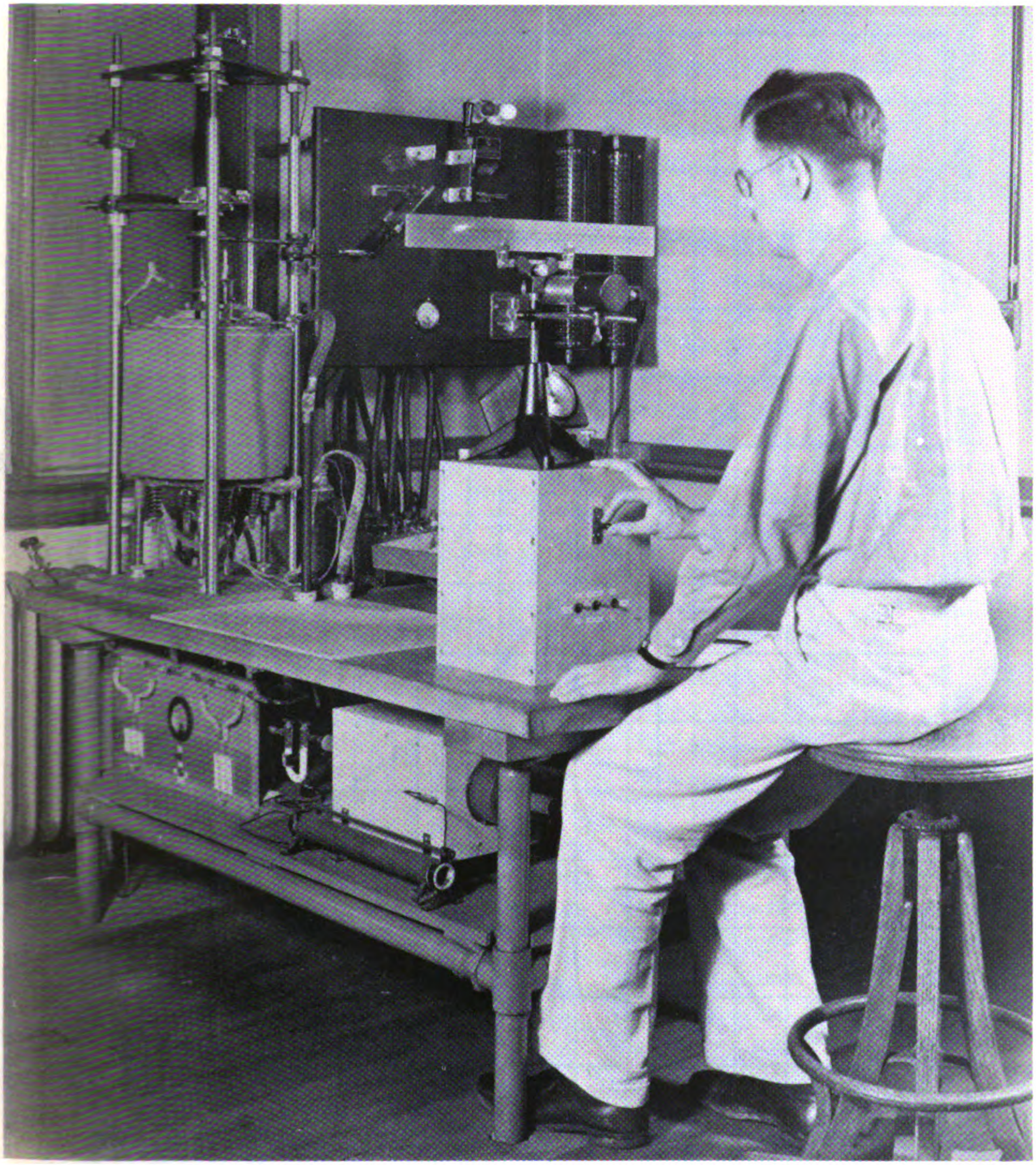

Figure 10.- Viscometer for coal-ash slags.

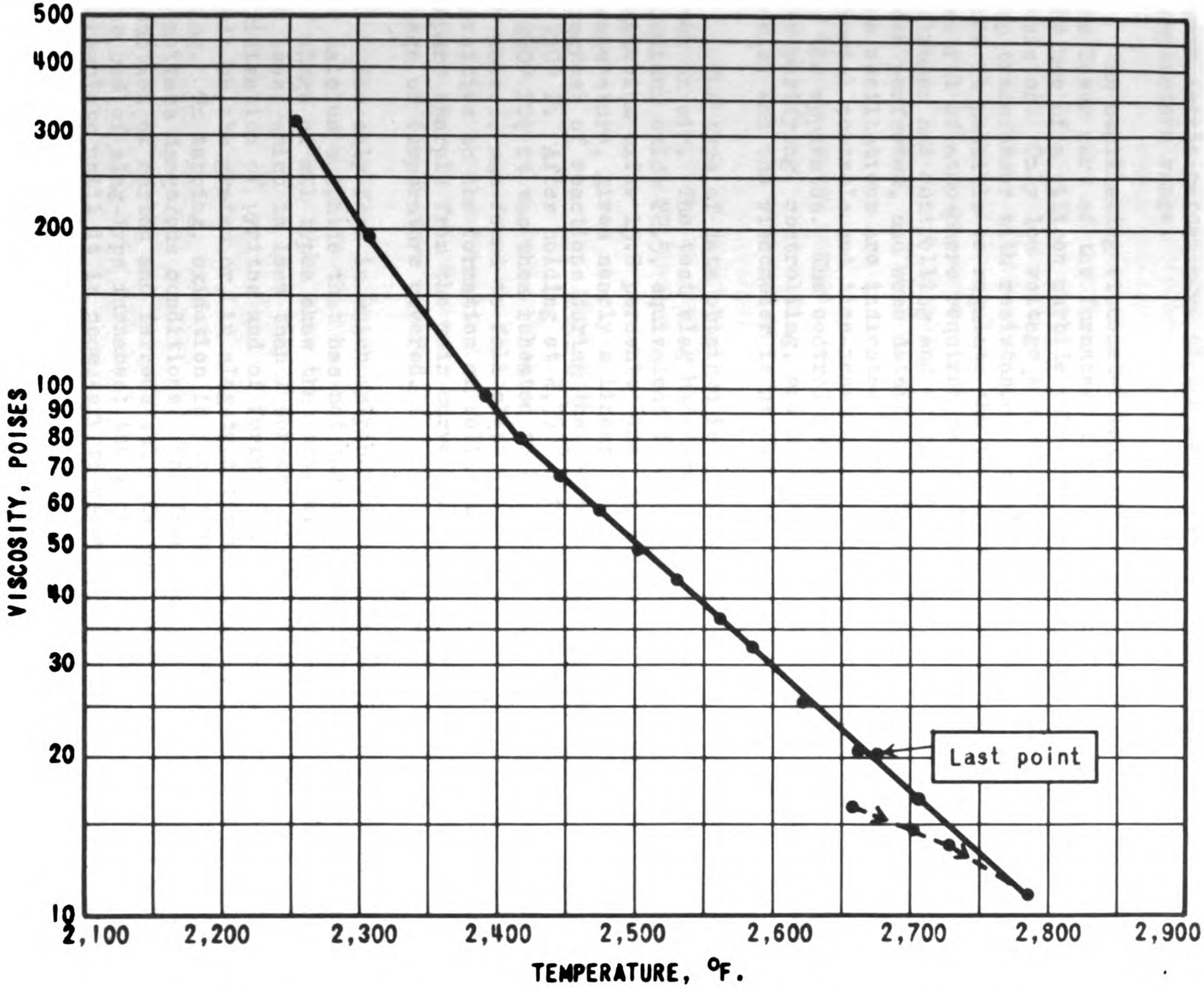

Figure 11.- Viscosity-temperature relationship of coal-ash slag.

The type of viscometer that can be used with slags must meet requirements in design for operation at a maximum temperature of not less than 2,900° F. and for control of the atmosphere surrounding the slag to insure known ferric percentages of the slag under test at any stage in the test-temperature range.

An oscillating viscometer was adopted because it permits sealing of the lower part of the furnace. The high temperature requirement was met by the use of a silicon carbide (Glo-bar) tube of 2-inch inside diameter as the resistor. Only low voltage was needed to operate the tube, and a multiple-tap transformer with resistances for close control of intermediate voltages made it possible to regulate the temperature within close limits. The control of atmosphere required rather elaborate apparatus for purifying the nitrogen and controlling and measuring its rate of flow. This has not yet been perfected, and some details are being changed. During measurements, the oscillations are indicated by the lamp-and-mirror principle, with special controls and time-measurement devices. Figure 10 is a photograph of the apparatus. The control switchboard is at the right; the equipment for purifying, controlling, and measuring the nitrogen is underneath the table; and the viscometer is at the left.

The type of data obtained is illustrated by figure 11 for a determination in air. The test slag had a composition of silicon dioxide 42.1, aluminum oxide 22.5, equivalent ferric oxide 21.4, and calcium oxide plus magnesium oxide 13.8 percent. The log-viscosity, in poises plotted against temperature, gives nearly a linear relationship. The dotted line shows the progress of reactions during the period of melting the slag, from 2,660° to 2,790° F. After holding at 2,790° for 1 hour, it was cooled, stepwise, to 2,260° F.; it was then reheated to 2,675° F. and the log-viscosity value, in poises, was found to fall close to the cooling curve. The method is sensitive to the formation of solid phases in the slag when test points depart sharply from the main curve. This slag had no solid phase in the range of temperature covered.

The only form in which sulphur is found in slags is entrained ferrous or calcium sulphide that has not had an opportunity to oxidize. Analyses of slags of all types show that the sulphur content is usually 0.1 percent or less, which is less than 1 percent of the sulphur in the coal. Insufficient oxidization of pyrites and of ferrous sulphide causes trouble because they melt on the grates or, in slag-type furnaces, are included in the molten slag. On tapping, oxidation is permitted, with resulting objectionable and sometimes dangerous conditions. The formation of metallic iron by the reaction of carbon and ferrous sulphide may cause trouble at the bottom of the bed of slag-type furnaces; the iron, because of its higher gravity, may accumulate until it is necessary to remove it by drilling.[76]

The treatment of coals with small quantities of chemicals to reduce slagging of boiler tubes can benefit only if a coating of chemical is deposited on the tubes and if this coating reduces the tendency of the slag particles to stick.[77]

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[76] Nicholls, P., Discussion of "The Significance to the Consumer of Sulphur in Coal" by H. Kreisinger: Proc. Am. Soc. Test. Mat., vol. 37, pt. 2, 1937, p. 373.

The laboratory ash-fusion and softening temperatures of a coal are important factors that should be considered in predicting the clinkering probability of a given coal. Attempts to make an all-inclusive correlation of the ash-softening temperature with other factors related to clinker formation generally have been unsatisfactory. However, the ash-softening temperature has proved to be of economic significance in the selection of coal, especially for plants that must operate under certain required conditions.[78] Careful consideration must be given to the restricted significance of the laboratory ash-fusion temperature in its relation to the evaluation of the action and effects of other more complex factors in explaining the two nonsynonymous expressions "tendency to clinker" and "trouble." A detailed analysis of all factors in relation to one another should be made.[79]

In cooperation with the American Society for Testing Materials, the Bureau is revising the standard method for determining coal-ash fusibility. The specific requirements of furnaces suitable for the test are being standardized and the use of either gas-fired or electrically heated furnaces that meet prescribed requirements as to temperature control and furnace atmosphere will be permitted. A Barrett coal ash-fusion furnace was installed at the Central Experiment Station to facilitate the increased demands for the coal ash-fusion determination.

Combustion in Stoker Fuel Beds

The development of a mathematical treatment for fuel beds was recommende as a good tool for expressing general relationships or to show the trend of varying the values of coefficients involved in the calculations. The suggestion was offered that a deduction of these coefficients from a series of suitable burning tests might simplify the mathematics required.[80]

The difficult task of the combustion engineer in observing accurately and interpreting logically the complicated mass-action conditions in different types of fuel beds in relation to the more restricted areas of laboratory investigations was pointed out.[81] The gap between the views of combustion engineers and of research engineers in analyzing factors in combustion will be bridged effectively only when these factors, including available test data such as ash-fusion temperature, knowledge of ash distribution and caking properties of the coal, temperatures, and distribution of air are correlated in proper perspective, one to another.[82]

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[77] Nicholls, P., Discussion of "Slag and Deslagging of Steam-Generating Equipment" by Alex. D. Bailey: Trans. Am. Soc. Mech. Eng., vol. 61, January 1939, sec. 1, p. 39.

[78] Barkley, J. F., Discussion of "The Significance of Ash-Softening Temperature and Ash Composition in the Utilization of Coal" by A. W. Gauger: Proc., Am. Soc. Test. Mat., vol. 37, pt. 2, 1937, pp. 393-394.

[79] Nicholls, P., Discussion of "The Significance of Ash-Softening Temperature and Ash Composition in the Utilization of Coal" by A. W. Gauger: Proc., Am. Soc. Test. Mat., vol. 37, pt. 2, 1937, pp. 396-398.

[80] Nicholls, P., Discussion of "Some Factors Affecting Combustion in Fuel Beds" by Martin A Mayers: Trans. Am. Inst. Min. and Met. Eng., Coal Div., vol. 130, 1938, p. 424.

Selection of proper coal for steam-generating equipment depends largely upon definite knowledge of the conditions to which the coal will be subjected in the furnace and how these conditions affect it. Selection based upon properties of coal must be correlated with plant requirements, design and adjustments of the stoker, and the furnace. Such information is gained most completely by cooperative effort of the combustion engineer, fireman, and research investigators.[83]

A comparatively recent development, the spreader-type stoker, has attracted the attention of engineers.[84]

The need for definitions of "coking", "hard coking", and "caking" and explanations of the initial causes in relation to over-all results with particular coals burned in underfeed stokers were emphasized.[85]

To study the burning of coals on a crossfeed principle, a special furnace has been designed for ignition of the upper surface of the fuel bed by radiation from globar units contained in a roof, which, after the ignition period, is replaced quickly by a second roof of refractory material.

Combustion on Domestic Stokers

The investigation of the burning characteristics of various ranks and sizes of Washington coals on a continuously operated residential-type overfeed stoker, begun last fiscal year at the Northwest Experiment Station, Seattle, Wash., in cooperation with the College of Mines of the University of Washington, has been extended to include other coals mined in Washington and Oregon and burned both continuously and intermittently.

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[81] Nicholls, P., Discussion of Papers in "Symposium on Coal Research": Proc., 19th Fuel Engineers' Meeting, Appalachian Coals, Inc., Cincinnati, Ohio, May 19, 1937, mimeographed, 2 pp.

[82] Nicholls, P., General Discussion at Conference of Fuel Engineers, Detroit, June 14, 1937: Proc. Fuel Engineers' Conference at Detroit, June 15, 1937, 3 pp.

[83] Nicholls, P., Discussion of "Status of Our Knowledge of Coal Selection for Steam-Generating Equipment" by R. A. Sherman: Mech. Eng., vol. 60, 1938, pp. 168-169.

[84] Barkley, J. F., The Forced Draft-Spreader Stoker: Trans. Am. Soc. Mech. Eng., vol. 59, 1937, pp. 259-265; discussion, vol. 60, 1938, pp. 438-448.

[85] Nicholls, P., Discussion of "Underfeed Stokers from the Standpoint of Coal Selection" by J. E. Tobey: Trans. Am. Soc. Mech. Eng., vol. 60, 1938, p. 369.

Thirty-eight burning trials were made during the present year on various sizes of eight coals, ranging in rank from high-volatile A bituminous to subbituminous B. With the modern type of hot-water boiler used, over-all efficiencies of 72 to 76 percent have been obtained consistently at burning rates of 12 to 15 pounds of coal per hour, even with coals of the lowest rank. At burning rates ranging from 20 to 24 pounds per hour, the efficiencies of the stoker-boiler combination ranged between 62 and 71 percent.

The most important fact brought out in a series of intermittent tests on two different coals, one series of which is shown graphically in figure 12, was that intermittent operation gave the same, or only slightly lower, over-all efficiencies as did continuous operation. Figure 12 also shows the relationship between the losses and the ratio of "time off" to "time on." The losses that decrease with increase in the time off are the dry flue gases, ashes, and moisture and hydrogen of the coal. The factor primarily responsible is the drop in flue-gas temperature with increase in the time off. The losses that increase with the time off are the undeveloped heat (combustible in flue gases) and the total of radiation and the unaccounted-for items. For convenience, figure 12 shows the total losses rather than the over-all efficiencies, which for this series remained nearly constant at about 71 percent.

The reason the efficiency of the stoker-fired boiler does not decrease with increase in the time the stoker is not operating probably is due not only to the characteristics of the boiler, as influenced by the load on it, but principally to the fact that there is a fire in the stoker retort throughout the off periods. The fire continues to act as an efficient, positive source of heat throughout long idle periods when fresh fuel is not being supplied - that is, when the stoker is not operating - a condition obviously possible only in the combustion of solid fuel.

A description of the testing plant, details of the procedure used, and complete heat-balance statements covering the first 26 burning trials made on two noncaking and two caking coals was published.86/

Graphic representations of the conditions in the fuel bed of an underfeed pot-type stoker burning a caking coal are recommended to show the nature of the burning, air distribution, and other factors.87/

86/ Yancey, H. F., Johnson, K. A., Lewis, A. A., and Cordiner, J. B., Jr., Burning of Various Coals Continuously and Intermittently on a Domestic Overfeed Stoker: Bureau of Mines Rept. of Investigations 3379, 1938, 29 pp. Excerpts entitled The Domestic Overfeed Stoker: The Miner, vol. 11, 1938, pp. 35-37; Overfeed Stokers Tested by Bureau of Mines: Heating and Ventilating - Air Conditioning, vol. 35, no. 6, June 1938, pp. 29-30.

87/ Nicholls, P., Discussion of "Combustion of Bituminous Coal on a Small Underfeed Stoker" by R. A. Sherman and E. R. Kaiser: Trans. Am. Inst. Min. and Met. Eng., Coal Div., vol. 1938, pp. 405-406.

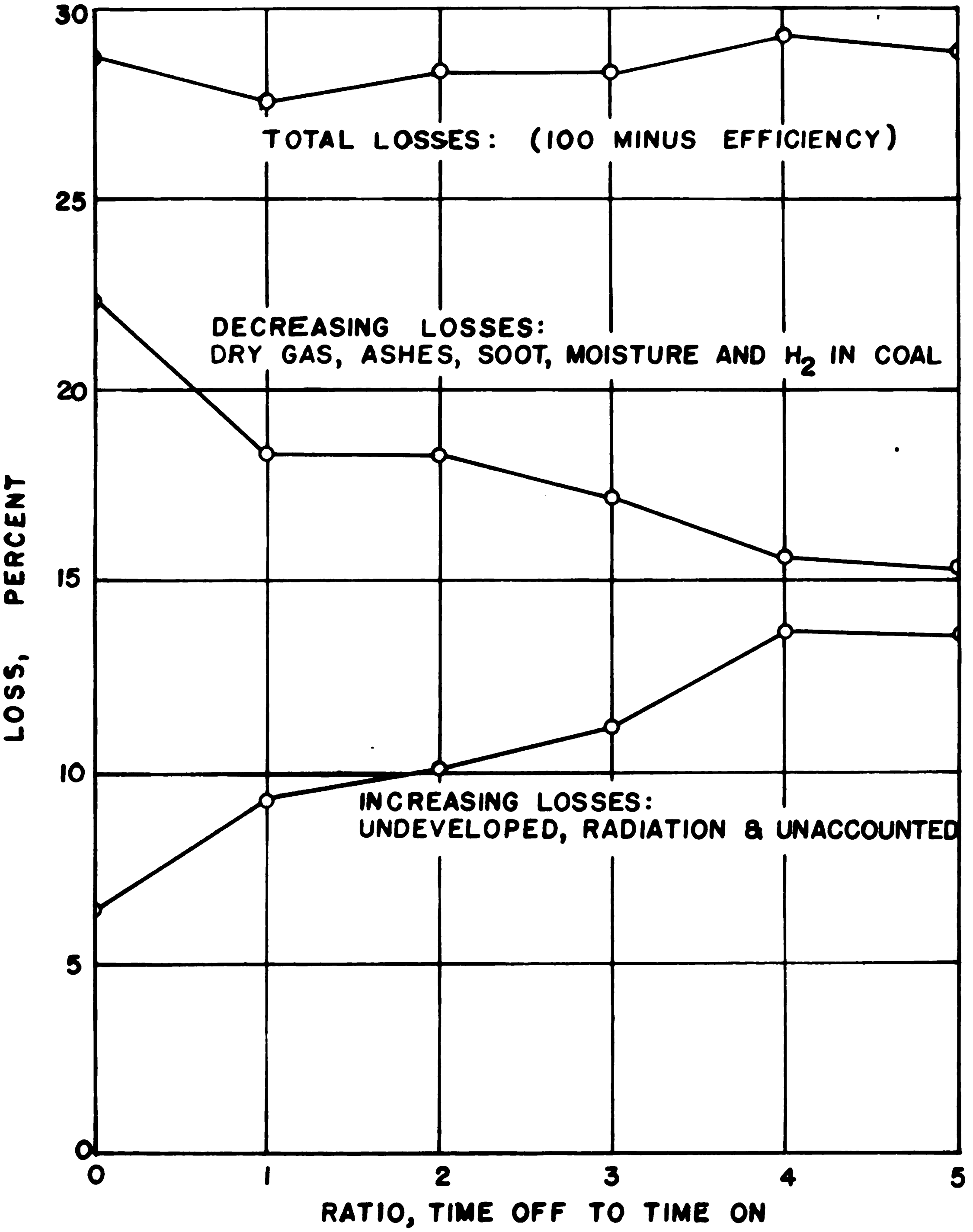

Figure 12.- Distribution of losses for intermittent operation of overfeed stoker.

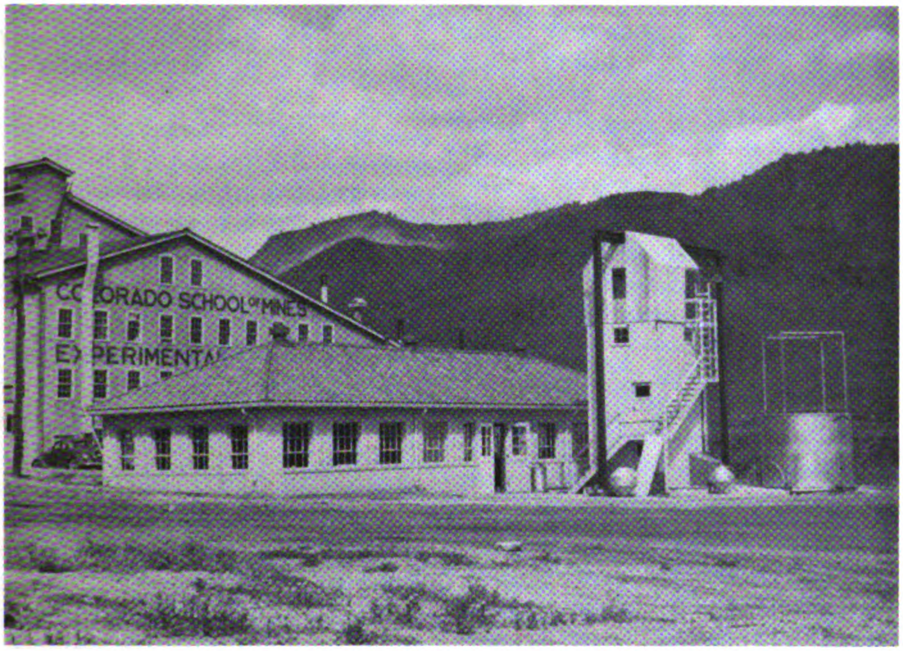

Figure 13.- Field station, Golden, Colo., May 1938.

The views of combustion engineers should be utilized by designers of stokers to overcome some of the mechanical troubles now known to be due to faulty design.[88]

Coke as a Domestic Fuel

The good features of coke as a domestic fuel and recommendations for its most efficient and economical firing practices were discussed.[89]

Studies of Subbituminous Coals and Lignite

A new field station[90] was established at Golden, Colo., on the campus of the Colorado School of Mines. A building, shown in the foreground of figure 13, constructed by the State of Colorado, was completed May 1, 1938.

The rapid deterioration and slacking of high moisture coals and possibilities of their spontaneous combustion present a difficult problem of storage. Mining of such coals, therefore, has been coincident with demand, thereby necessitating increased mining capacity on the one hand and creating seasonal unemployment on the other. This poor-load factor is reflected in higher prices for these high-moisture coals. To study this problem of storage as well as to store control samples of subbituminous coals and lignites for experimentation on combustion and processing, two concrete bins, each of 50 tons capacity, hermetically sealed and provided with instruments for measuring conditions of storage, have been erected.

Because of the small domestic heating market for subbituminous coal and lignite - only about 7 percent of the total domestic coal market annually in the United States - the manufacturers of domestic heating appliances have paid but little attention to improvement of devices for burning the noncoking, high-oxygen coals. Consequently, many domestic users of these coals have been forced in many instances to use improperly designed heating equipment.

A cooperative study of the drying of lignite by the Fleissner process on a pilot-plant scale has been undertaken by the Bureau and the University of North Dakota.

Properties of Western Cokes or Chars

Carbonization of a typical subbituminous coal from the Puritan mine, Dacono, Weld County, Colo., was made primarily to obtain information for guidance in the design, construction, and testing of the Heliopore process proposed for carbonizing coal by the exhaust heat from a gas engine. The carbonization tests were conducted in the usual manner by the BM-AGA test method. Subsequent tests were made on the properties of the chars obtained, including measurements of fixed gases when heated to successively higher temperatures, contraction of the chars as related to temperature of heating, the amount of degradation of the char when reheated, and data on the proximate and ultimate analyses of the chars produced under various conditions. The investigation showed:[91]

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[88] Barkley, J. F., Discussion of "Small Underfeed Single Retort Stokers" by G. M. Guthrie: Trans. Am. Soc. Mech. Eng., vol. 60, 1938, p. 363.

[89] Nicholls, P., Coke as a Domestic Fuel. Published in mimeographed form by Michigan Retail Coal Merchants: Proc. Fuels Utilization Institute, Univ. of Michigan, May 1938 (mimeographed).

[90] Parry, V. F., Bureau of Mines Field Station, Golden, Colo.: Bull. Colorado Society of Engineers, June 1938, 3 pp.

1. The yields of products at low temperatures (500° and 600° C.) are consistent with yields calculated from the proximate analysis.

2. When carbonized at temperatures above 600° C., the high concentration of water in the products of distillation promotes the water-gas reaction, which at 900° C. accounts for half the volume of gas formed and 35 percent of the potential heat in the gas.

3. The chars show a total shrinkage of 30 to 40 percent of the charge as a result of carbonization; those produced at 500° C. contain 14 percent volatile matter, which when heated to 900° C. give 8,800 cubic feet of gas per ton of char and containing 66 percent of hydrogen.

4. The coal is absolutely noncoking and disintegrates considerably when carbonized; a disintegration of 25 percent occurs when it is heated to 550° C., and this increases with increase in temperature of carbonization.

Survey of the Carbonizing Properties of American Coals

This work includes both laboratory carbonization assays and Bureau of Mines-American Gas Association retort carbonization tests. The laboratory assays are made as routine tests on coals tested in connection with the BM-AGA retort survey work on the gas-, coke-, and byproduct-making properties of American coals and, in addition, on a number of other coals.

Laboratory carbonization assays at both low and high temperatures were made on 38 coals to determine their coking characteristics and the yields of coke, gas, and byproducts that might be expected in commercial coking practice. Twenty-five of these coals were from Alabama, and these completed a survey of the chemical and physical properties of Alabama coals that was begun during the preceding year. The Alabama coals tested were of high-volatile A and medium-volatile bituminous rank. Yields of coke and byproducts obtained were normal for coals of these ranks, although differences in yields were noted for coals from different fields and beds. In general, those coals containing the highest fixed carbon yielded the most coke and the least tar and light oil. No relationship could be established between fixed-carbon contents and yields of gas on a B.t.u. per pound of coal basis. Examination of the coked residues showed that considerable variation in coke

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[91] Davis, J. D., and Parry, V. F., Carbonizing Properties of a Subbituminous Coal from Puritan Mine, Dacono, Weld County, Colo.: Bureau of Mines Report of Investigations 3428, 1939, 32 pp.

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quality is to be expected from various coals of Alabama. The results of the laboratory carbonization assay tests together with the analyses, grindability, and friability tests of the Alabama coals will be published soon.

During the past year several publications were issued (or are in press) on investigations conducted the previous year on the gas-, coke-, and byproduct-making properties of American coals.[92] Table 2 gives the sources of 8 new coals and of 2 blending coals, together with the analyses of these and of 14 blends prepared therefrom, which were tested during the present year.

Classified according to rank,[93] coals 47, 48, 50, and 51 are low-volatile bituminous, coals 52 and 53 are bright high-volatile A bituminous, coal 54 is a splint high-volatile A bituminous, coal 49 is subbituminous, and coals 28 and 41 are high-volatile A and low-volatile bituminous blending coals, respectively.

Particular attention should be directed to coals 52 and 54. Table 2 shows these coals to be of the same calculated rank (59.9 percent of dry, mineral-matter-free fixed carbon). They differ markedly, however, in their petrographic composition: The Bruceton coal (no. 52) contains 84 percent of bright, 13 percent of semisplint, and 3 percent of splint coal, whereas the High Splint coal (no. 54) consists of 53 percent splint, 14 percent semisplint, and only 33 percent of bright coal.

Table 3 shows that this difference in petrographic composition is reflected in (1) the comparative strengths of their cokes, (2) their sensitivity to oxidation, as measured by the strength of coke, and (3) their blending properties with Beckley coal. Except for the hardness factor (tumbler test cumulative percentage upon 1/4-inch screen) on the 500° and 800° C. cokes, all shatter and tumbler indexes show that the cokes from the bright coal (no. 52) are stronger than correspondingly prepared cokes from the splint coal (no. 54). The coke from this bright coal tends generally to yield a larger percentage of finer material in the tumbler test.

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[92] Davis, J. D., and Holmes, C. R., Blending of Certain High-Volatile Coals with Beckley Bed Coal and the Effect on the Yield and Quality of Carbonization products: Proc. Am. Gas. Assoc., 1937, pp. 670-681.
Fieldner, A. C., Davis, J. D., Thiessen, R., Selvig, W. A., Reynolds, D. A., Holmes, C. R., and Sprunk, G. C., work cited in footnote 26, p. 8.
Fieldner, A. C., Davis, J. D., Thiessen, R., Selvig, W. A., Reynolds, D. A., Brewer, R. E., and Sprunk, G. C., work cited in footnote 27, p. 8.

[93] American Society for Testing Materials, work cited in footnote 3, p. 5.

TABLE 2. - Analyses of coals, as carbonized[1]

Coal 47 - Lower Kittanning bed (unwashed), No. 72 mine, Cambria County, Pa.
Coal 48 - Lower Kittanning bed (washed), No. 72 mine, Cambria County, Pa.
Coal 49 - Puritan mine, Weld County, Colo.
Coal 50 - Upper Kittanning bed (unwashed), No. 73 mine, Cambria County, Pa.
Coal 51 - Upper Kittanning bed (washed), No. 73 mine, Cambria County, Pa.
Coal 52 - Pittsburgh bed, Bruceton mine, Allegheny County, Pa.
Coal 53 - Pond Creek bed, Majestic mine, Pike County, Ky.
Coal 54 - High Splint bed, Clover splint mine, Harlan County, Ky.
Coal 28 - Pittsburgh bed, Warden mine, Allegheny County, Pa.
Coal 41 - Beckley bed, Winding Gulf No. 1 mine, Raleigh County, W. Va.

Coal[2]	Dry, mineral-matter-free, fixed carbon	Moist, mineral-matter-free B.t.u.	Analyses, percent									Heating value, B.t.u. per pound	Softening temperature of ash, °F.
			Proximate				Ultimate						
			Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulphur		
47	82.9	15,520	1.7	16.3	75.3	6.7	4.4	82.5	1.4	3.7	1.3	14,310	2,670
47A	67.5	15,030	1.7	30.6	62.0	5.7	5.2	79.7	1.5	6.8	1.1	14,070	2,660
47B	69.1	15,040	1.9	29.0	63.3	5.8	5.1	79.9	1.6	6.4	1.2	14,060	2,660
48	83.0	15,270	2.9	16.1	75.3	5.7	4.6	82.8	1.4	4.7	.8	14,300	2,910+
48A	66.9	15,070	1.7	31.2	61.8	5.3	5.3	80.2	1.5	6.7	1.0	14,180	2,740
48B	69.2	15,010	1.8	29.2	63.6	5.4	5.3	80.3	1.5	6.5	1.0	14,100	2,790
49	61.6	10,580	19.7	29.4	46.4	4.5	6.0	58.3	1.3	29.5	.4	10,050	2,060
50	82.1	15,480	1.8	16.9	72.0	9.3	4.5	79.1	1.2	3.6	2.3	13,860	2,380
50A	65.9	15,150	1.8	31.8	60.1	6.3	5.2	78.8	1.5	7.0	1.2	14,080	2,590
50B	67.7	15,100	2.3	30.0	61.2	6.5	5.2	78.8	1.5	6.8	1.2	14,000	2,610
51	81.5	15,440	2.2	17.3	72.0	8.5	4.5	80.2	1.4	4.2	1.2	13,980	2,660
51A	67.0	15,020	1.9	30.9	61.2	6.0	5.2	79.3	1.6	6.8	1.1	14,010	2,670
51B	68.6	15,150	1.6	29.4	62.5	6.5	5.0	79.5	1.6	6.3	1.1	14,050	2,670

(See footnotes on following page.)

TABLE 2. - Analyses of coals, as carbonized[1] - Continued.

Coal 47 - Lower Kittanning bed (unwashed), No. 72 mine, Cambria County, Pa.
Coal 48 - Lower Kittanning bed (washed), No. 72 mine, Cambria County, Pa.
Coal 49 - Puritan mine, Weld County, Colo.
Coal 50 - Upper Kittanning bed (unwashed), No. 73 mine, Cambria County, Pa.
Coal 51 - Upper Kittanning bed (washed), No. 73 mine, Cambria County, Pa.
Coal 52 - Pittsburgh bed, Bruceton mine, Allegheny County, Pa.
Coal 53 - Pond Creek bed, Majestic mine, Pike County, Ky.
Coal 54 - High Splint bed, Clover splint mine, Harlan County, Ky.
Coal 28 - Pittsburgh bed, Warden mine, Allegheny County, Pa.
Coal 41 - Beckley bed, Winding Gulf No. 1 mine, Raleigh County, W. Va.

Coal[2]	Dry mineral-matter-free, fixed carbon	Moist, mineral-matter-free, B.t.u.	Analyses, percent									Heating value, B.t.u. per pound	Softening temperature of ash, °F.
			Proximate				Ultimate						
			Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulphur		
52	59.9	14,860	2.4	36.6	53.2	7.8	5.1	75.8	1.5	8.2	1.6	13,560	2,510
52A	64.4	15,030	2.0	33.0	58.1	6.9	5.1	78.0	1.5	7.2	1.3	13,870	2,510
52B	66.3	14,990	2.3	31.2	59.9	6.6	5.1	78.4	1.5	7.1	1.3	13,880	2,530
53	66.1	15,010	2.7	31.9	61.1	4.3	5.3	80.5	1.5	7.7	.7	14,290	2,890
53A	68.5	15,130	2.3	29.7	63.6	4.4	5.1	81.4	1.4	7.0	.7	14,390	2,890
53B	70.1	15,200	2.0	28.4	65.3	4.3	5.1	82.1	1.4	6.5	.6	14,470	2,910
54	59.9	14,470	3.3	37.5	55.5	3.7	5.5	78.3	1.4	10.6	.5	13,870	2,280
54A	63.9	14,690	2.7	34.0	59.5	3.8	5.2	79.8	1.4	9.3	.5	14,070	2,360
54B	66.1	14,690	2.7	32.0	61.6	3.7	5.3	80.3	1.4	8.8	.5	14,080	2,550
28B[3]	62.3	15,050	2.1	35.3	57.2	5.4	5.5	79.2	1.6	7.3	1.0	14,140	2,620
28C[4]	61.9	15,020	1.9	35.6	56.9	5.6	5.5	78.9	1.5	7.6	.9	14,080	2,670
41[5]	81.3	15,470	2.3	17.9	76.0	3.8	4.6	85.3	1.4	4.5	.4	14,820	2,919+

[1] Analyses by H. M. Cooper, chemist, Bureau of Mines. [2] Coals 47A and 48A contain 80 percent and coals 47B and 48B contain 70 percent of Pittsburgh bed (Warden mine) coal (no. 28B); coals 50A and 51A contain 80 percent and 50B and 51B contain 70 percent of Pittsburgh bed (Warden mine) coal (no. 28C). Coals 52A, 53A and 54A contain 20 percent and coals 52B, 53B and 54B contain 30 percent of Beckley bed coal (no. 41). [3] Sampled February 1936 and used in blending with coals 47 and 48. [4] Sampled July 1937 and used in blending with coals 50 and 51. [5] Used in blending with coals 52, 53, and 54.

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TABLE 3. - Comparison of shatter and tumbler indexes of coke from Bruceton coal with that from High Splint coal

Coal 52 - 100 percent Bruceton.
Coal 52A - 80 percent Bruceton and 20 percent Beckley.
Coal 52B - 70 percent Bruceton and 30 percent Beckley.
Coal 54 - 100 percent High Splint.
Coal 54A - 80 percent High Splint and 20 percent Beckley.
Coal 54B - 70 percent High Splint and 30 percent Beckley.

Coal	Retort diameter, inches	Carbonizing temperature, °C.	Shatter test, cumulative percent upon -			Tumbler test, cumulative percent upon -			
			2-inch screen	1½-inch screen	1-inch screen	2-inch screen	1½-inch screen	1-inch screen	¼-inch screen
52	13	500	71.4	82.5	91.2	9.7	30.7	44.2	52.0
54	13	500	62.4	74.5	81.8	4.0	15.7	25.5	34.6
52	13	600	55.3	73.9	86.3	.0	6.7	30.4	54.3
54	13	600	47.1	65.4	80.1	.0	1.6	20.4	56.2
52	13	700	58.2	71.7	84.6	.4	7.2	28.2	57.5
54	13	700	49.5	63.2	77.4	.0	.7	12.9	66.4
52	13	800	59.7	76.2	86.4	.0	14.1	34.7	59.7
54	13	800	48.1	70.3	84.4	.0	6.0	29.2	67.1
52	18	800	64.7	76.6	87.5	3.4	15.9	33.8	61.8
54	18	800	56.0	73.9	84.0	.3	8.6	26.0	66.2
52 1/	18	800	64.0	78.4	86.5	.0	11.8	33.4	62.2
54 2/	18	800	39.3	53.1	63.5	.0	1.6	16.8	41.8
52 3/	18	800	63.1	75.4	85.6	.3	10.6	29.3	50.4
54 4/	18	800	31.8	47.3	58.5	.0	1.1	8.8	39.1
52	13	900	40.1	67.1	87.8	.0	11.0	39.6	62.5
54	13	900	25.1	53.9	84.5	.0	3.6	35.7	72.3
52	18	900	37.6	67.4	87.1	.2	10.3	38.8	66.0
54	18	900	31.0	63.2	85.3	.0	6.7	37.7	70.8
52A	18	900	53.6	79.0	92.1	3.5	26.9	52.2	68.0
54A	18	900	49.4	74.1	92.0	1.6	19.2	54.5	73.2
52B	18	900	57.5	84.7	94.1	2.0	27.3	55.3	70.5
54B	18	900	46.7	75.5	93.8	2.0	23.8	57.8	74.0
52	18	1,000	22.4	55.9	85.6	.0	4.4	34.2	65.8
54	18	1,000	18.5	46.6	83.8	.0	1.7	34.0	74.5

1/ Oxidized 9 days at 100° C.
2/ Oxidized 6 days at 100° C.
3/ Oxidized 15 days at 100° C.
4/ Oxidized 10 days at 100° C.

Blending with Beckley coal increases the shatter indexes (1-1/2 inches) of 18-inch retort 900° C. cokes from the two coals to about the same extent; but the increase in the tumbler index (1 inch) is greater for the High Splint (no. 54) coal. For example, in the blends containing 20 percent Beckley there is a 44.6-percent increase in tumbler index for the High Splint, compared with 34.5 for the Bruceton; for the 30-percent blends, the corresponding increases are 53.3 and 42.5 percent, respectively.

Oxidation of the two coals under like conditions affects the coke from the High Splint much more than that from the Bruceton coal. For example, the 1-1/2-inch shatter and 1-inch tumbler indexes of coke (from the 18-inch retort at 800° C.) from fresh Bruceton coal are 76.6 and 33.8 percent, respectively; oxidation for 9 days at 100° C. slightly increases the former and leaves the latter about the same. Corresponding indexes for coke from fresh High Splint coal are 73.9 and 26.0, and oxidation for only six days lowers them to 53.1 and 16.8. Continued oxidation has a proportionally greater effect on the High Splint than on the Bruceton coal; oxidation of High Splint coal for 10 days lowers the shatter and tumbler indexes to 47.3 and 8.8 percent, respectively; oxidation of Bruceton coal for 15 days only lowers these indexes to 75.4 and 29.3 percent. These tests show that the splint coal is not only weakly coking, as compared with a bright coal of equal rank, but also what coking power the splint possesses originally is more easily destroyed by oxidation or weathering.

Results of the investigations of the BM-AGA surveys on the gas-, coke-, and byproduct-making properties of coals 47 to 54, inclusive, are in manuscript form or in press.[94]

The process of caking and coking in fuel beds differs from that in coke ovens in that the pieces of coal are in a partly or totally oxidizing atmosphere, so that the amount of caking and the size of the pieces of coke formed are dependent on the air rate. At low rates, the fusion of coal can close the free spaces between pieces soon enough so that the coking of the coal mass should follow the process in an oven. With increased air flow the volatile binding materials are either burned or carried away, and if the air flow is high enough caking is prevented at those interstices through which air can pass. Numerical measurements of the relative caking and coking properties in a fuel bed are difficult to make, and close correlation with the observed characteristics of caking and coking as determined in a non-oxidizing atmosphere cannot now be expected. Some qualitative measurements on fuel beds appear promising.95/

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[94] Fieldner, A. C., Davis, J. D., and others, Carbonizing Properties and Petrographic Composition of Washed and Unwashed Lower and Upper Kittanning Bed Coals from Bethlehem Steel Co. Mines 72 and 73, Johnstown, Cambria Co., Pa.: Bureau of Mines Tech. Paper 595 (in press).
Davis, J. D., and Parry, V. F., work cited in footnote 92, p. 30.
Fieldner, A.C., Davis, J. D., and others, Carbonizing Properties and Petrographic Composition of Pittsburgh Bed Coal from Bureau of Mines Experimental Mine, Bruceton, Allegheny Co., Pa.: Bureau of Mines Tech. Paper 594 (in press).
Fieldner, A. C., Davis, J. D., and others, Carbonizing Properties and Petrographic Composition of Pond Creek Bed Coal from Majestic Mine at Majestic in Pike County, Kentucky: Bureau of Mines Tech. Paper 596 (in press).
Fieldner, A. C., Davis, J. D., and others, Carbonizing Properties and Petrographic Composition of High Splint Bed Coal from the Closplint Mine, Closplint, Harlan County, Kentucky: Bureau of Mines Tech. Paper 599 (in press).

The agglutinating value is not always an accurate criterion for predicting the coking behavior of blends of different proportions of low- and high-volatile coals. However, it indicates the ratio of splint to bright coal in a given coal; the agglutinating value is usually, though not always, low for splint coal.96/

Composition of Coal Tar and Light Oil

A review of the published information, with selected bibliography on the chemical and physical properties of light oil and coal tar produced under both low- and high-temperature conditions, was published.97/

Effect of Conditioning on the Coking Properties of Coal

To reduce the time-consuming procedure involved in studying the oxidation of coal under storage conditions, the rate of oxidation has been accelerated in an especially designed apparatus. This apparatus, shown in figures 14 and 15, was designed and built to obtain oxidation data on each coal as it is received for test in the BM-AGA survey of the carbonizing properties of American coals. It consists essentially of a large rotating drum so jacketed that when heated externally by a suitable boiling liquid, the temperature of the drum interior is maintained constant. The liquid is heated by means of a gas burner, and a reflux condenser returns the condensate to the jacket.

Four hundred pounds of coal, crushed to pass a 1/4-inch screen, is placed in the drum. The half-filled drum is then rotated at eight revolutions per hour while air is passed over the coal. The entering air is measured by a wet-test meter and the exit gases are sampled periodically by a solenoid automatic sampler. These samples are composited and at desired stages are analyzed. From this, the total amount of oxygen used by the coal is calculated. Corresponding to these stages, samples of coal are riffled out for carbonization in both the BM-AGA test apparatus and in a 4-pound retort. The rest of the coal is returned to the drum for further oxidation. Sampling of the exit gas and of coal for BM-AGA and 4-pound retort carbonization test samples was described in an earlier publication.98/

95/ Nicholls, P., Discussion of "Laboratory Tests Relating to Caking, Plastic, Gas- and Coke-Making Properties of Bituminous Coals" by O. O. Malleis: Proc. Am. Soc. Test. Mat., vol. 37, pt. 2, 1937, p. 417.

96/ Davis, J. D., Discussion of "Laboratory Tests Relating to Caking, Plastic, Gas- and Coke-Making Properties of Bituminous Coals" by O. O. Malleis: Proc. Am. Soc. Test. Mat., pt. 2, vol. 37, 1937, p. 417.

97/ Fisher, C. H., Composition of Coal Tar and Light Oil: Bureau of Mines Bull. 412, 1938, 70 pp.

98/ Schmidt, L. D., Elder, J. L., and Davis, J. D., Oxidation of Coal at Storage Temperatures - Effect on Carbonization Properties: Ind. and Eng. Chem., vol. 28, 1936, pp. 1346-1353.

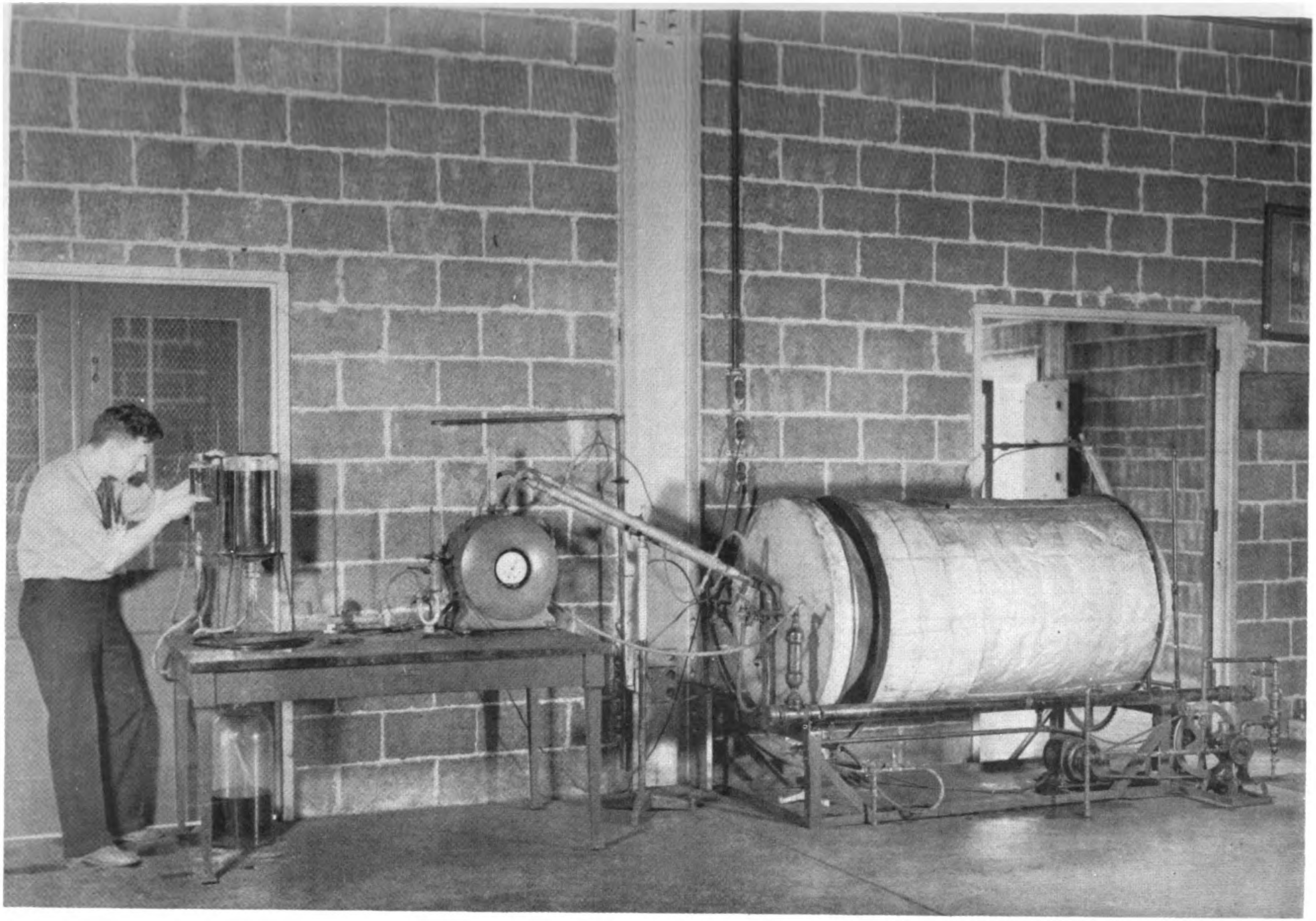

Figure 14.- Large-unit coal-oxidation apparatus.

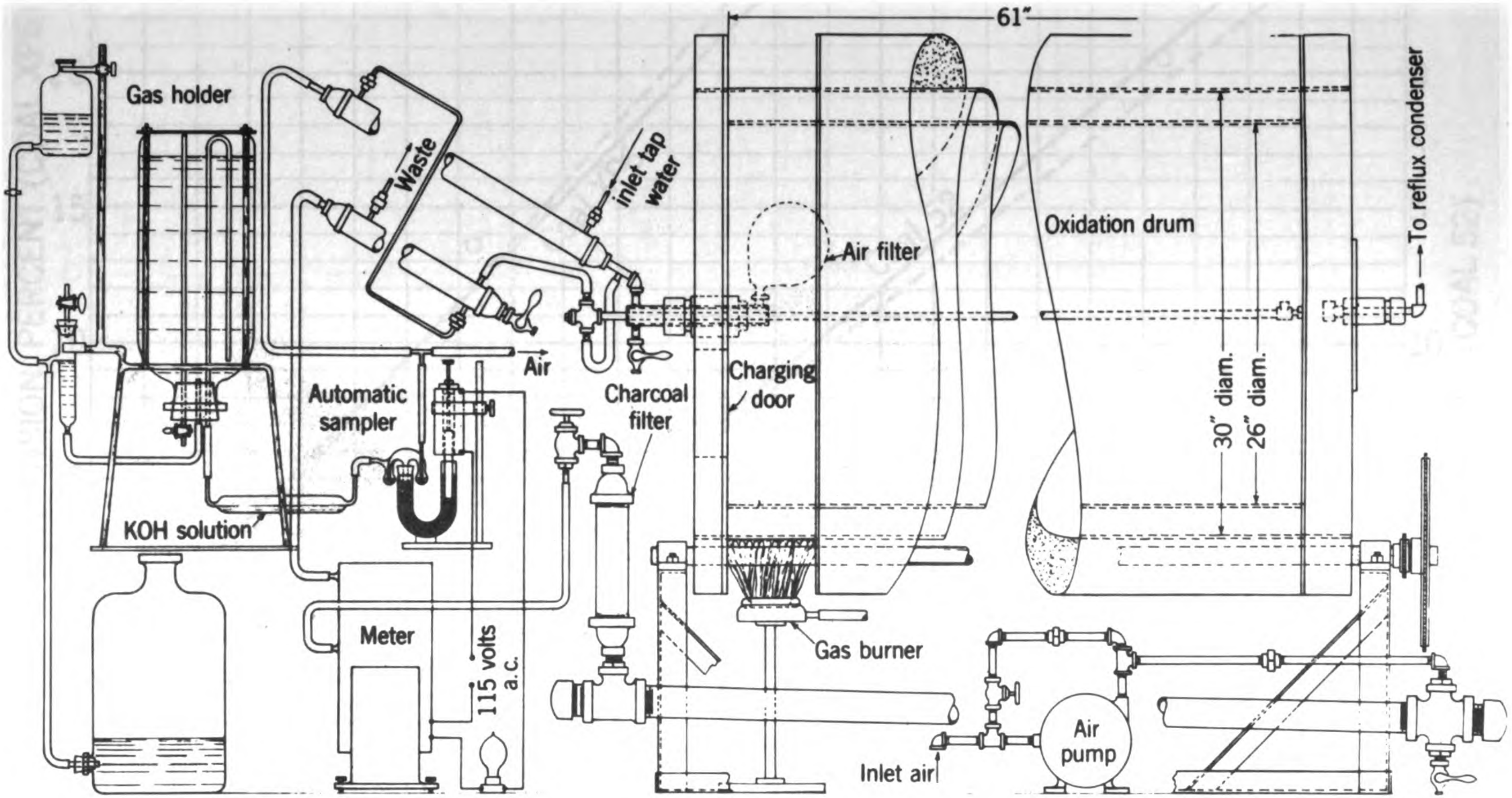

Figure 15.- Plan of large-unit coal-oxidation apparatus.

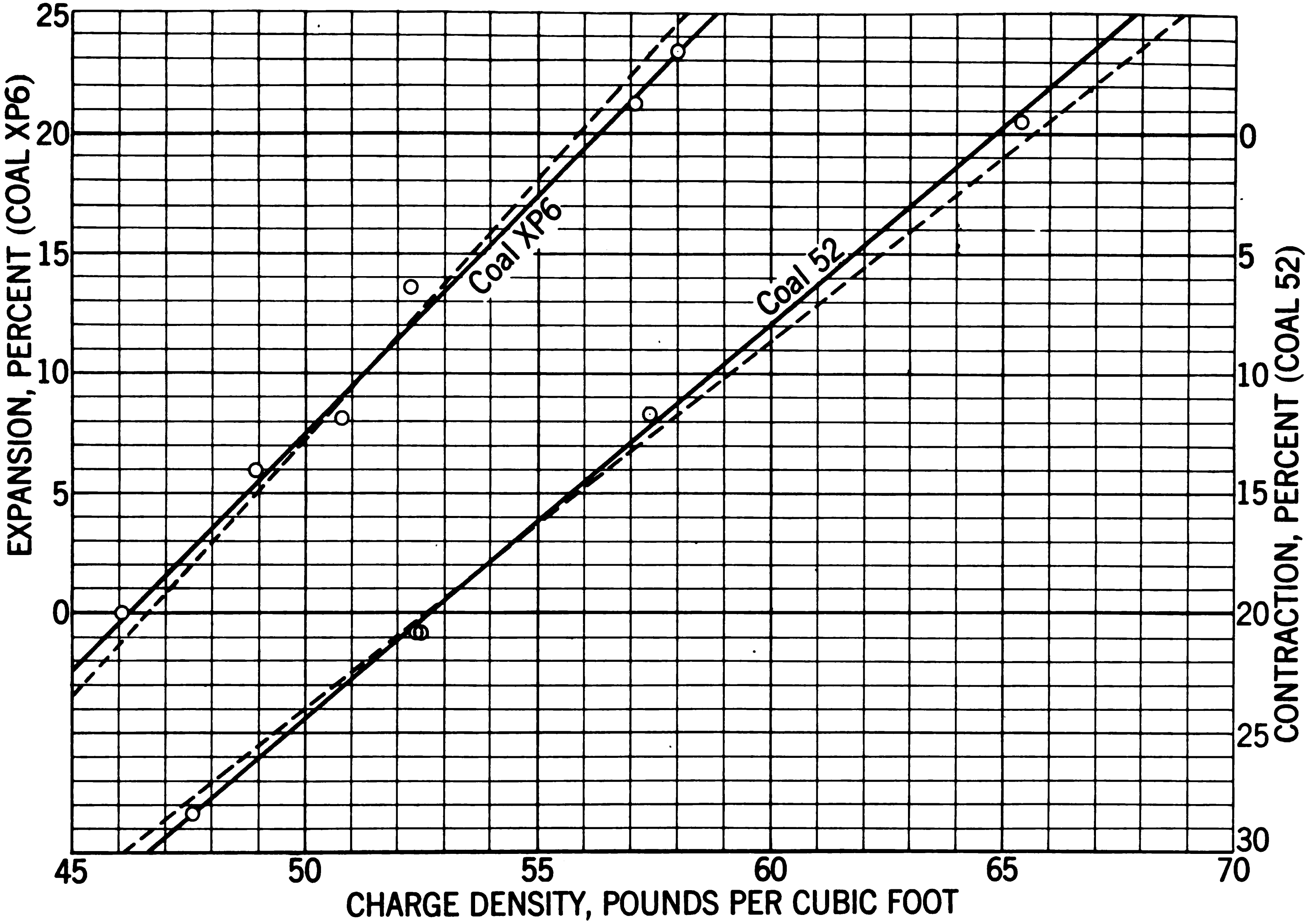

Figure 16.- Variation of expansion (and contraction) with density of charge.

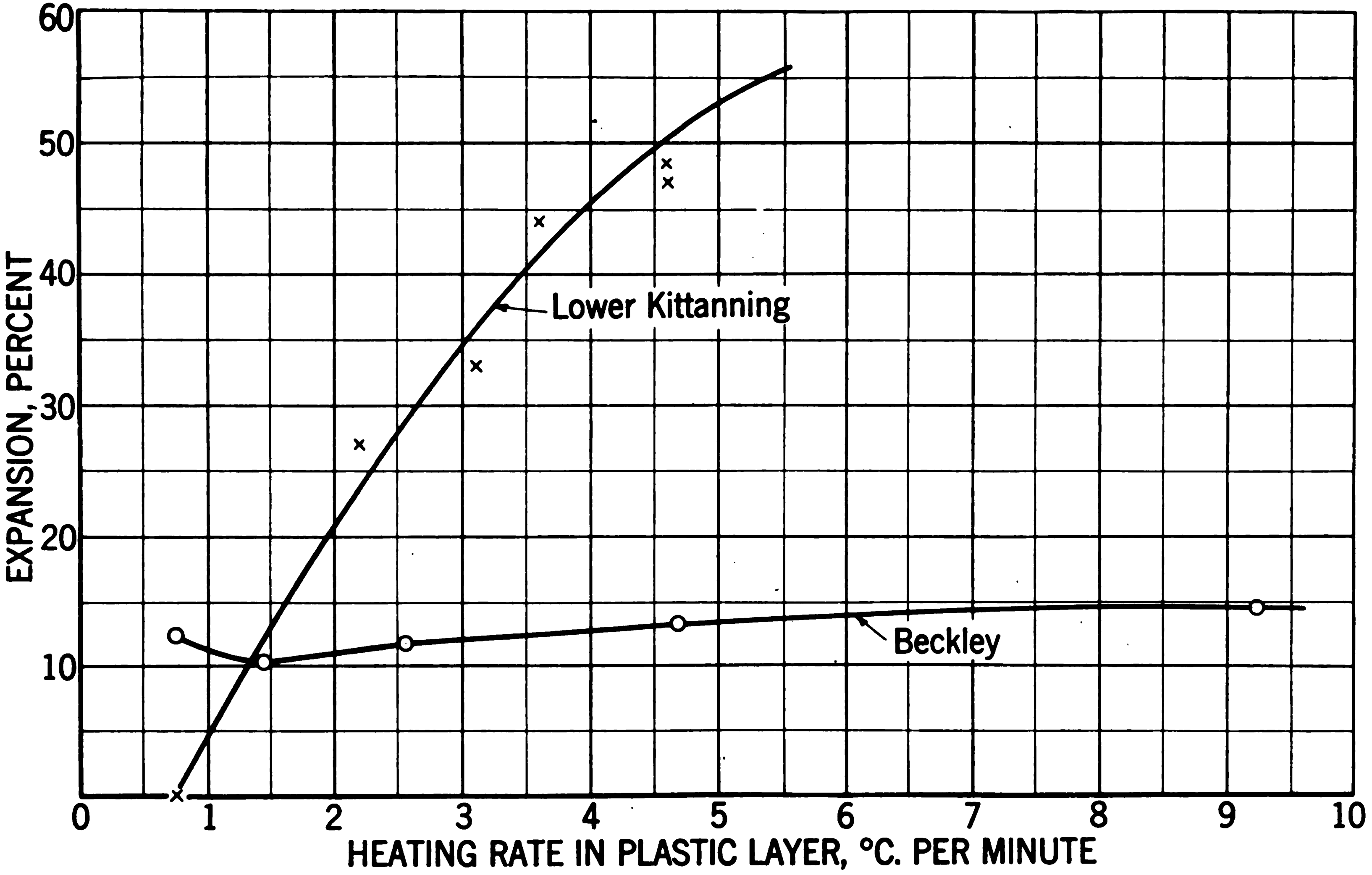

Figure 17.- Effect of heating rate on expansion.

Four coals from different beds have now been tested for their behavior upon oxidation. Listed in the order of increasing rate of oxidation, these are (1) Lower Kittanning, (2) Pond Creek, (3) Pittsburgh, and (4) High Splint. The rate of oxidation of High Splint was double that of Lower Kittanning coal. Pittsburgh bed coal was oxidized at 30°, 50°, and 99.3° C. It was found that the rate of oxidation increased by a factor of about 1.7 for each 10° C. rise in temperature.[99] All four coals showed a large decrease in tar yield upon oxidation, and all except High Splint showed an initial increase in coke strength followed by decreasing strength. If oxidation is continued long enough "pebbly" coke results, and further oxidation brings about complete loss of coking power.

Swelling of Coals During the Coking Process

The two methods of the Bureau, described in the report of last year, for predetermining the probable expanding (or contracting) properties of coals and blends to be expected when they are coked in commercial ovens have been used during the present fiscal year in studies of the effect on expansion of variations in carbonizing conditions.[100]

Conclusions reached from these studies were:

1. The expansion (or contraction) obtained on coking a charge of coal is practically a straight-line function of the density of charge. Figure 16 illustrates this fact. From these data and the true specific gravity of a coal, the expansion at other densities of charge can be calculated to a close approximation.

2. The expansion of a coal is also practically a straight-line function of the common logarithm of the load under which it is coked. The load on the bottom portion of the charge in a high oven is greater than that in a low oven. One may expect, therefore, that coals coking safely in low ovens might have dangerous expanding properties in high ovens.

3. Figure 17 shows that the rate of heating through the plastic range of temperature may affect the expansion of a coal markedly or it may affect it only slightly. Comparable rates of heating in the test procedure and coke-oven practice for a particular coal should be observed, particularly for those coals found to be sensitive to changes in rate.

4. Laboratory studies have shown that during the coking process shrinkage takes place at temperatures below that at which the coal becomes plastic and always at temperatures between semi-coke formation and final

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[99] Schmidt, L. D., and Elder, J. L., Atmospheric Oxidation of Coal at Moderate Temperatures. I. Rate of the Oxidation Reaction for Representative Coking Coals: To be published in Ind. and Eng. Chem.

[100] Auvil, H. D., and Davis, J. D., Determination of the Swelling Properties of Coal During the Coking Process: Bureau of Mines Rept. of Investigations 3403, 1938, 18 pp.

oven temperatures. It may be concluded, therefore, that if a coal expands during the process, it does so while it is within the plastic range of temperature (approximately 400° to 480° C. for most coals). Over this range gases and tars are evolved in quantity, and the difficulty these products encounter in escaping from the heated coal mass is believed to be the cause of expansion[101]. That is, the more viscous is the plastic coal, the greater will be the expansion. This work has been substantiated also by the Bureau's own laboratory tests of plastic properties.

5. It is recommended that one of the Bureau's or some other suitable test procedure for measuring expansion (or contraction) of coals during coking be used routinely on borderline coals or blends that expand dangerously under some, but not under other, coke-plant carbonizing conditions. The test procedure used should be modified to simulate the conditions of coking in the particular plant on all coals, but most particularly on borderline coals and blends proposed for commercial coking.

Hydrogenation of Coal

During the year the experimental plant has been expanded, and some changes have been introduced since last year's report was made and since the last publication[102] describing the plant was issued. A new publication[103], now in press, describes briefly the new construction additions and the incorporated changes in equipment and earlier procedures. A second paper[104] has been prepared, which described in detail the experimental coal-hydrogenation plant and the results of an assay of Pittsburgh bed, Bruceton mine, coal. It seems desirable, however, to present here a complete description of the plant as of June 1, 1938. For convenience of description, the experimental plant may be divided into two parts, namely, the hydrogen-production plant and the coal-liquefaction plant.

Description of Experimental Hydrogen-Production Plant

Figure 18 shows a flow diagram of the hydrogen-production unit. Pittsburgh natural gas containing about 90 percent methane, 8 percent ethane, 0.5 percent higher hydrocarbons, and 1.5 percent nitrogen, is mixed with about 1.5 times its volume of steam. This mixture enters the water-gas generator, where the temperature is 900° to 1,050° C. (1,650° - 1,920° F.). The following reactions occur:

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[101] Koppers, H., The New Koppers Expansion Apparatus: H. Koppers G.m.b.H., Essen, Germany, 12 pp. Kauermann, Essen, Margarethenhohe.

[102] Storch, H. H., Hirst, L. L., Golden, P. L., Pinkel, I. I., Boyer, R. L. Schaeffer, J. R., and Kallenberger, R. H., U. S. Bureau of Mines Experimental Plant: Ind. and Eng. Chem., vol. 29, 1938, pp. 1377-1380.

[103] Hirst, L. L., Hawk, C. O., Golden, P. L., Pinkel, I. I., Boyer, R. L., Schaeffer, J. R., Kallenberger, R. H., Hamilton, H. A., and Storch, H. H., Liquid-Phase Hydrogenation of Pittsburgh Seam Coal in Bureau of Mines Experimental Plant: To be published in Ind. and Eng. Chem.

[104] Storch, H. H., and Fieldner, A. C., Coal Hydrogenation, Bureau of Mine Experimental Plant: Presented before joint meeting of the Fuels Division, A.S.M.E., and the Coal Division, A.I.M.E., Chicago, October 13 and 14, 1938: To be published in Trans. Am. Soc. of Mech. Eng.

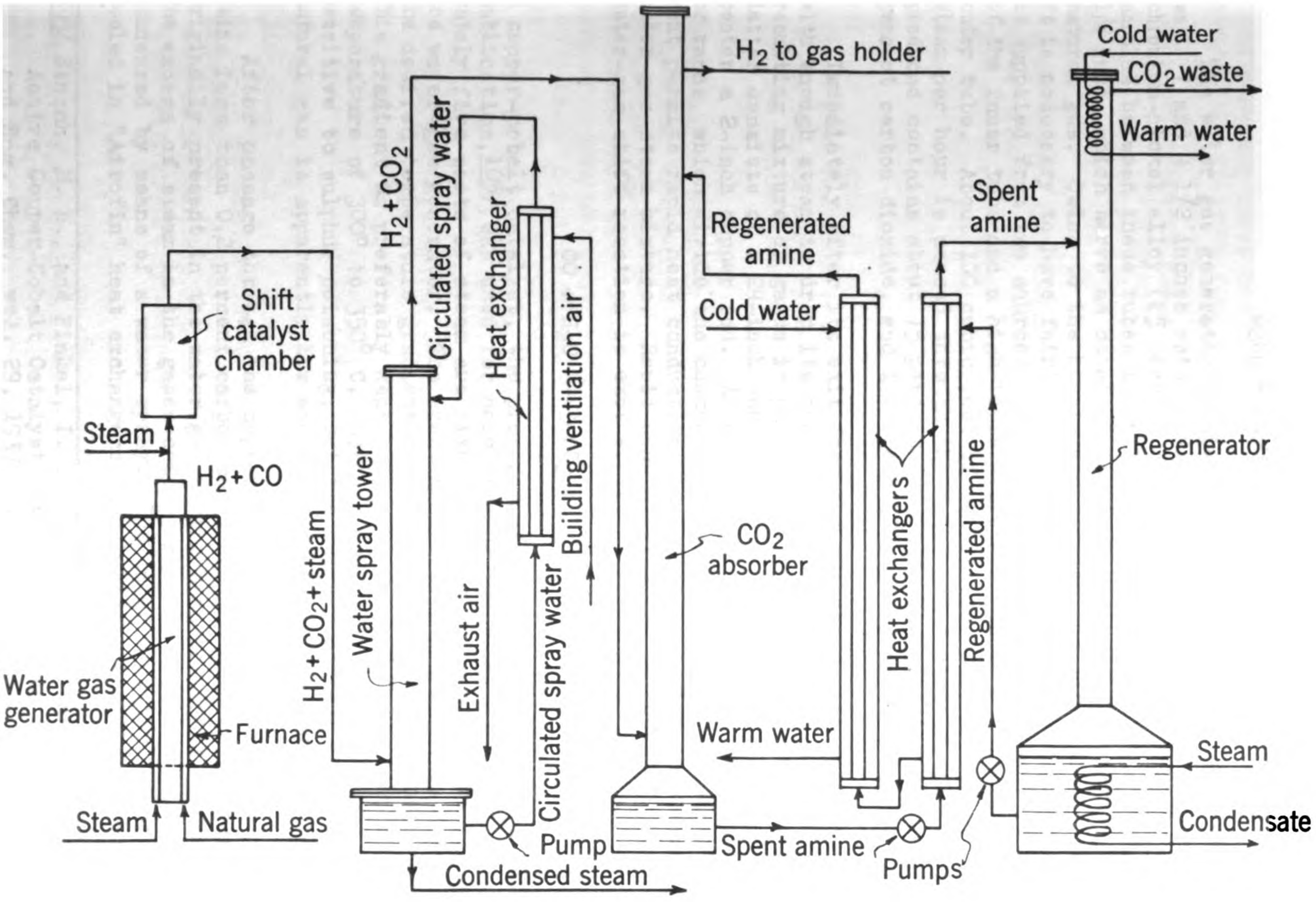

Figure 18.- Schematic flow diagram, hydrogen-production unit, Bureau of Mines Experimental Coal Hydrogenation Plant, Pittsburgh, Pa.

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$$CH_4 + H_2O \longrightarrow CO + 3H_2$$

$$C_2H_6 + 2H_2O \longrightarrow 2CO + 5H_2$$

The water gas generator consists of two concentric tubes of 1/4-inch wall, 7 and 4 1/2 inches outside diameter, and 60 inches long, made of high chromium-nickel alloy (25 percent chromium, 20 percent nickel). The 1-inch annulus between these tubes is filled with pure nickel stampings, 1/4 by 1/8 inch, which serve as catalyst for the reaction between the steam and natural gas. Owing to the highly endothermic character of the reactions, it is necessary to have fairly rapid heat transfer. For this reason, heat is supplied from two sources, namely, a 1.5-inch Glowbar unit in the center of the inner tube and a high-temperature resistance heater surrounding the outer tube. About 100 cubic feet of natural gas and 150 cubic feet of steam per hour is passed through the water-gas generator. The water gas produced contains about 75 percent hydrogen, 21 percent carbon monoxide, 1 percent carbon dioxide, and 1 percent nitrogen plus methane.

Immediately after its exit from the generator, the water gas is mixed with enough steam to drop its temperature to about 300° C. (570° F.). The resulting mixture of gases is passed into the water gas shift chamber. The latter consists of a 24-inch section of 6-inch steel pipe containing at its center a 2-inch copper rod. Attached to the latter are eight copper plates or vanes, which divide the chamber into eight catalyst spaces. This arrangement permits rapid heat conduction and avoids excessive channeling of the water gas-steam mixture. Rapid heat dissipation is necessary because the water-gas shift reaction is exothermic:

$$CO + H_2O \longrightarrow CO_2 + H_2 + 10 \text{ kg-cals.}$$

A copper-cobalt catalyst, the preparation of which is described in a separate publication,[105] was used for accelerating the water-gas reaction. Approximately five parts of steam are mixed with the water gas as it issues from the water-gas generator. The exact amount of steam added is determined by the desired temperature gradient in the column of copper-cobalt catalyst. This gradient is preferably kept below 50° C. (90° F.) - that is, a catalyst temperature of 300° to 350° C. (572° to 662° F.). The catalyst is very sensitive to sulphur poisoning, but the sulphur content of Pittsburgh natural gas is apparently low enough to make purification unnecessary.

After passage through the copper-cobalt catalyst, the gas mixture contains less than 0.2 percent carbon monoxide, the bulk of the carbon monoxide originally present in the water gas having been converted to carbon dioxide. The excess of steam in the gases coming from the copper-cobalt catalyst is condensed by means of a water spray. The water used for this spray is cooled in "Airofin" heat exchangers, the building ventilation air (10,000

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[105] Storch, H. H., and Pinkel, I. I., A Method for the Preparation of an Active Copper-Cobalt Catalyst for the Water Gas Shift Reaction: Ind. and Eng. Chem., vol. 29, 1937, p. 715. (U. S. Patent 2118329, May 31, 1938.)

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cubic feet per minute) being used as the cooling fluid. The spray tower is 8 inches by 8 feet, with a reservoir 24 by 12 inches attached to its base.

Carbon dioxide is removed in an 8-inch by 17-foot tower packed with 1/4-inch carbon Raschig rings, over which a 10-percent tetramine solution flows. A 24- by 12-inch reservoir is attached to the base of this tower. Tetramine is mainly a mixture of diethylenetriamine and triethylenetetramine. The amine solution is regenerated by boiling and fractionating in a column packed with 1/4-inch carbon Raschig rings. The boiler is 36 by 24 inches and the column 8 inches by 13 feet.

A photograph of the exterior of the coal-hydrogenation laboratories is shown in figure 19. The carbon dioxide-free hydrogen is collected in the 500-cubic foot gas holder, which may be seen at the extreme right of figure 19. A view of the hydrogen-plant interior is shown in figure 20. To the left is the water-gas generator with the water-gas shift chamber immediately above it. To the right in the foreground is the amine regenerator and behind it is the carbon dioxide absorption tower. Along the back wall of the plant is the amine heat exchanger, and immediately in front of this are the flowmeters for measuring gas, steam, amine, and water flow rates. The amine pumps may be observed under the amine regenerator and the carbon dioxide absorption towers. The water-spray tower is not visible, being immediately behind the water-gas generator.

The 400 to 500 cubic feet per hour of hydrogen produced by the plant described above contains about 0.2 percent carbon monoxide, 1.5 percent nitrogen plus methane, 0.1 percent carbon dioxide, 0.2 percent oxygen, and 98 percent hydrogen. It is compressed to about 1,800 pounds and stored in steel cylinders at this pressure until used in the coal-hydrogenation plant. The hydrogen plant has functioned very satisfactorily during a total production of about 60,000 cubic feet of hydrogen. At the end of this period cracks developed in the outer tube at the level of the top weld of the water-gas generator. Upon investigation, it was found that the alloy-steel used in this weld had a much higher expansion coefficient than the material of which the tubes were constructed. The metal of the outer tube below the welded region showed no signs of rupture.

Description of Coal-Liquefaction Plant

Figure 21 is a flow diagram of the coal-liquefaction plant. Coal is ground in a ball mill after being mixed with an equal weight of heavy oil, 0.25 percent of tin sulphide, and 0.25 percent of molybdic oxide, until most of the solid particles will pass through a 200-mesh sieve. The coal-oil paste is delivered under several pounds pressure by a gear-type oil pump to the high-pressure paste pump. The latter is a vertical piston pump with steel-ball check valves and adjustable stroke.

The paste is forced into the converter, which is a tube, 5 inches outside diameter and 3 inches inside diameter, made of 18-percent chromium- and 8 percent nickel-alloy steel.

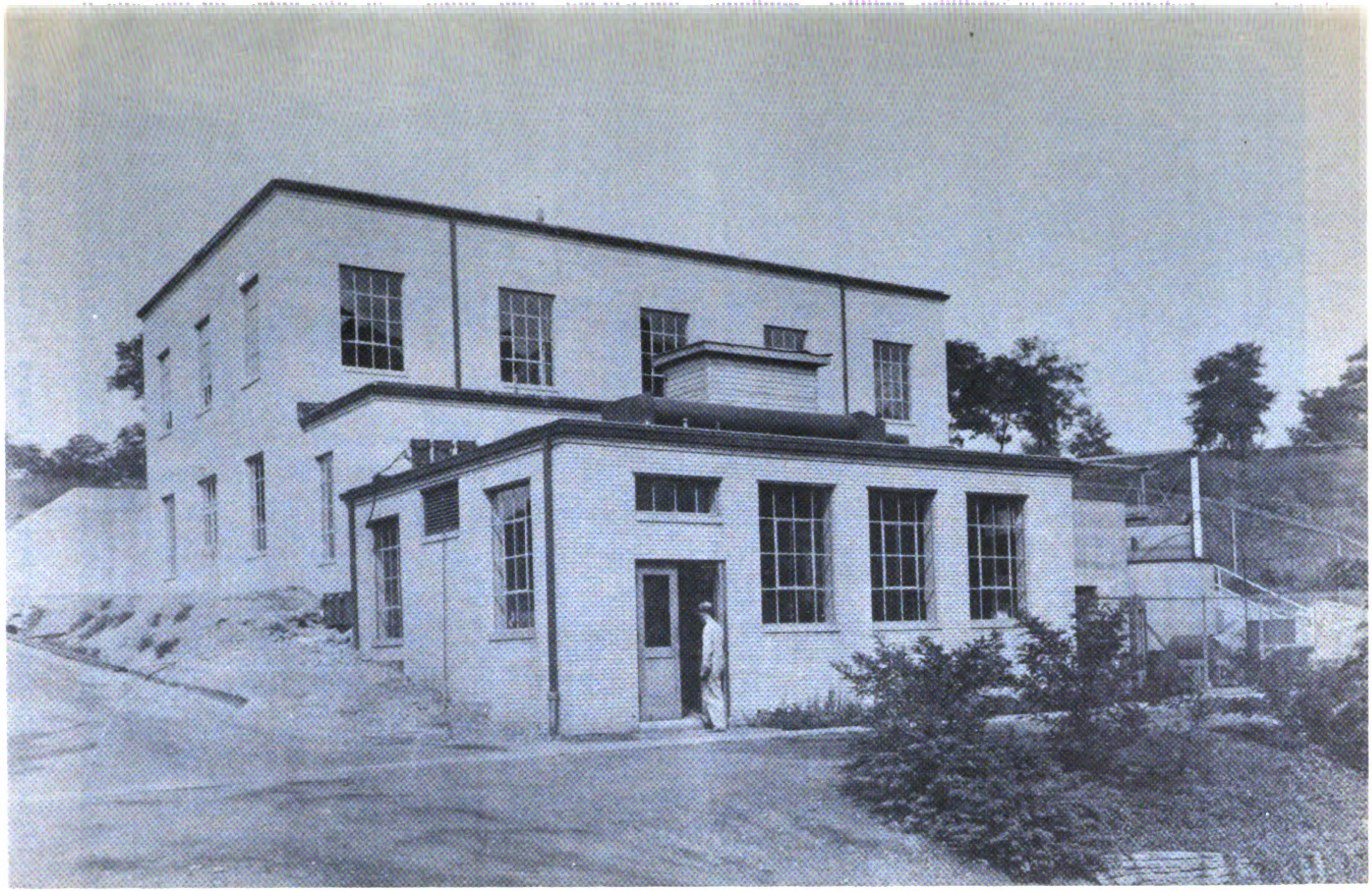

Figure 19.- Exterior view of experimental hydrogenation plant.

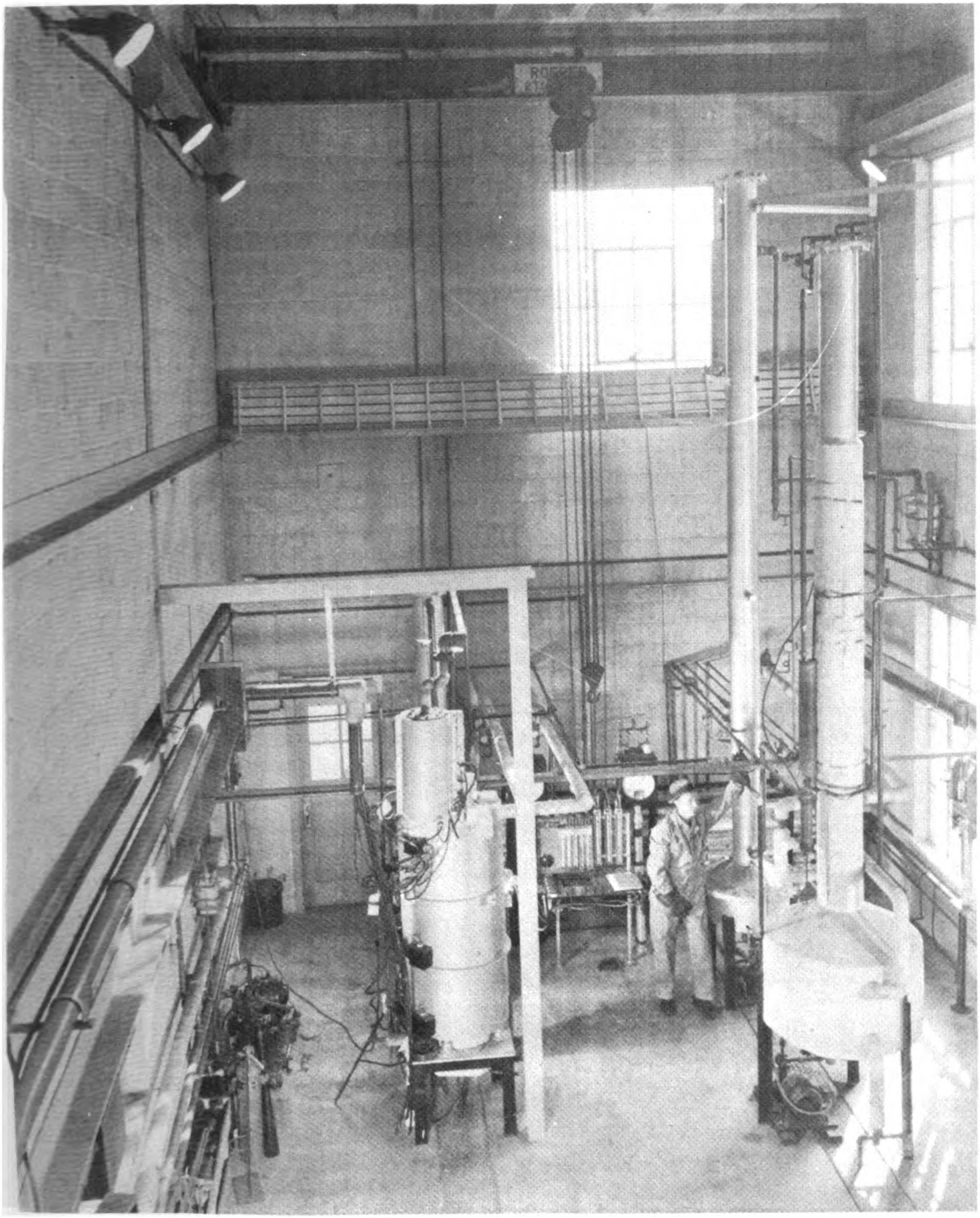

Figure 20.- Interior view of experimental hydrogen-production unit.

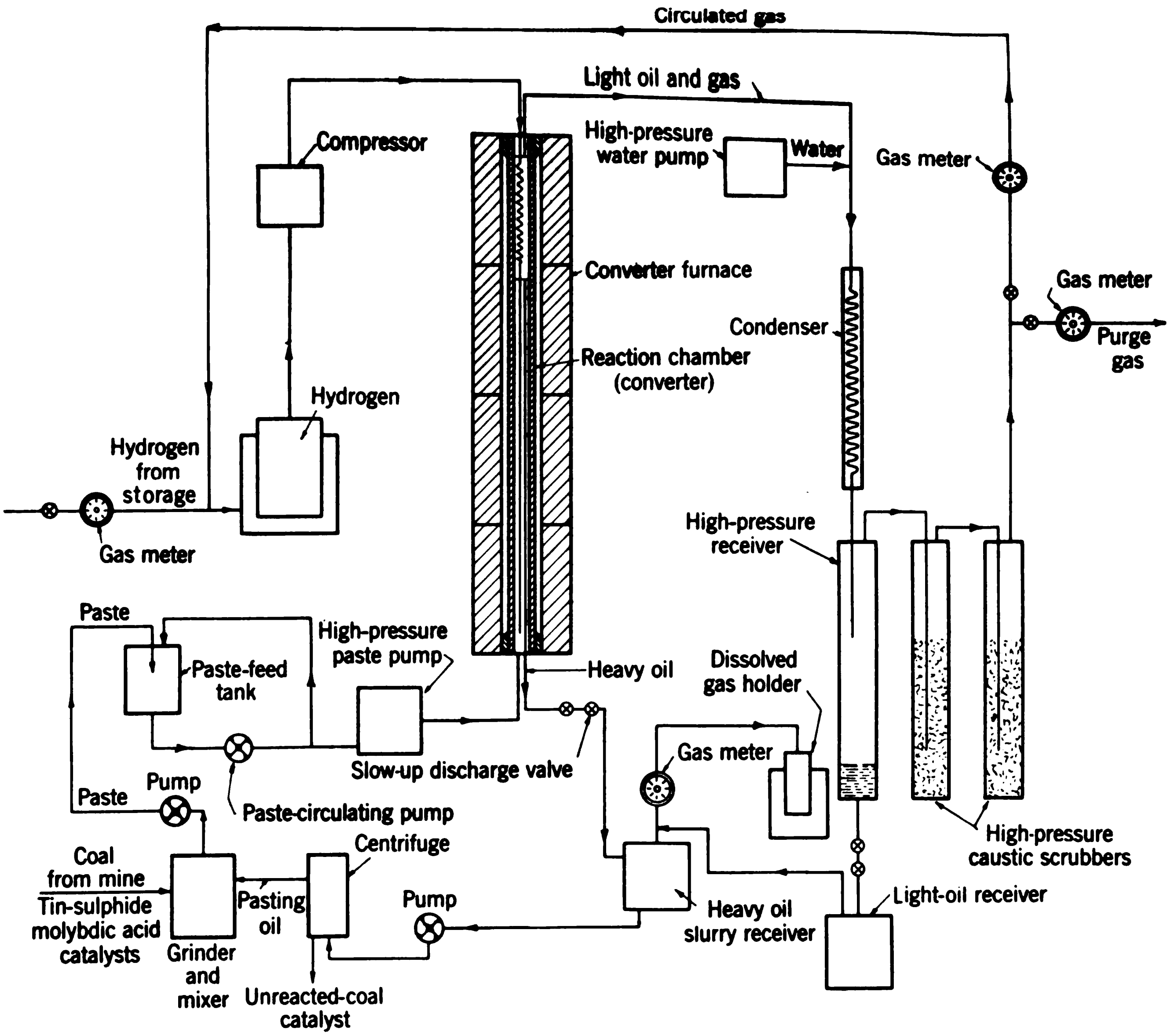

Figure 21.- Schematic flow diagram, Bureau of Mines Experimental Coal Hydrogenation Plant, Pittsburgh, Pa.

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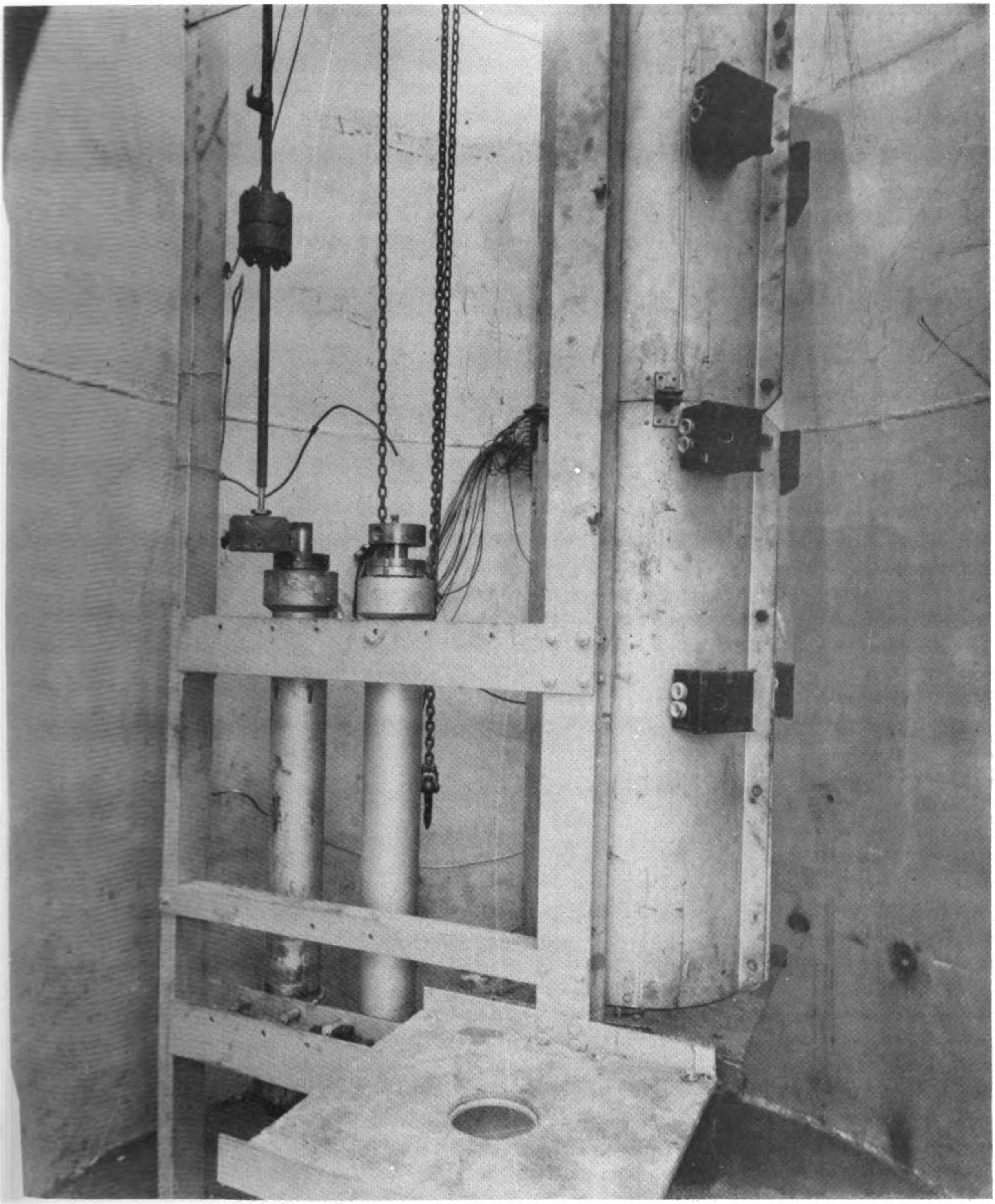

Figure 22.- Trap for receiving cooled overhead oil and hydrogen and caustic scrubber for hydrogen.

Coal-oil (equal parts by weight) paste is pumped into the converter at the rate of 5 to 10 pounds per hour, the rate depending upon the reaction temperature, which is usually between 420° and 450° C. (788° and 842° F.). Hydrogen is pumped in at the rate of about 100 cubic feet (measured at atmospheric pressure and temperature) per hour. The excess hydrogen over that absorbed by the coal is recirculated by the high-pressure recirculation pump.

The heavy oil overflows into the standpipe inside the converter and is discharged through a specially designed valve.

The heavy oil discharge consists of a slurry of a material resembling a primary coal tar with the ash of the coal and unreacted coal particles suspended in it. To facilitate discharge, all the valves and discharge pipes are heated by steam jackets to about 100° C. (212° F.). This slurry is diluted with about 30 percent of its volume of a middle oil obtained by fractional distillation of the converter overhead oils and is then centrifuged. The centrifuged oil is used to provide the vehicle for producing the mixture of coal and oil at the head of the process.

The oil vapors carried through the top of the converter by the unreacted hydrogen gas consist of about 20 percent of light oil boiling below 200° C. and 80 percent of a middle oil boiling up to 330° C. This overhead oil plus hydrogen is passed through a water-cooled condenser and then into one of the traps shown in figure 22. The hydrogen gas is scrubbed by passage over solid caustic soda in the second trap of gifure 22 to remove hydrogen sulphide before the gas is admitted to the recirculation pump. The recirculation gas contains about 10 percent of hydrocarbons, the proportion of these being controlled by the rate of gas purging.

Hydrogenation Assay of Bruceton Coal

During the year quantitative procedures for the hydrogenation assay of American coals have been developed. This work involved the perfection of mechanical equipment for continuous operation of the experimental plant, the training of operators for each of the three shifts, and the development of feasible quantitative tests. All of the work was done on Pittsburgh bed coal from the Bureau's Experimental mine at Bruceton, Pa.

The assay consists in determining the optimum conditions in liquid-phase hydrogenation for the maximum yield of a "middle" oil consistent with the complete regeneration of the vehicle used in making a paste with the original coal. For Bruceton coal, the optimum conditions are approximately 440° C., 200 to 300 atmospheres pressure, 1.75 hours contact time, and a circulation time of about 100 cubic feet (measured at atmospheric pressure) per hour of hydrogen. Under these conditions, a yield of about 73 percent of "middle" oil (containing 20 percent boiling in the gasoline range and 80 percent boiling below 330° C. (626° F.) and 12 to 15 percent of hydrocarbon gases (methane to butane) is obtained in a single pass through the converter. The 12- to 15-percent loss consists of 6 to 8 percent of unreacted carbonaceous material and 6 to 7 percent of oxygen, nitrogen, and sulphur hydrogenated to water, ammonia, and hydrogen sulphide, respectively. The "middle" oil contains 15 to 18 percent of tar acids and 3 to 5 percent of tar bases, and the remaining neutral oil consists of 6 to 8 percent olefins, 67 to 70 percent aromatics, and 22 to 27 percent saturated hydrocarbons. The forthcoming papers[106] should be consulted for further details.

Because Bruceton coal is to be used as a standard coal, much more work was done with it than is planned for other coals. Future experience will suggest additional detailed investigations upon, or the development of new hydrogenation procedures for, this coal.

Small-Bomb Experiments

Rates of liquefaction and of removal of oxygen, nitrogen, and sulphur. - Figure 23 is a photograph of the apparatus used in small-bomb hydrogenation studies. Results of tests on the rates of removal of oxygen, nitrogen, and sulphur from Pittsburgh bed, Bruceton mine, coal have been published.[107] Hydrogenation in a tetrahydronaphthalene was carried out for different lengths of time (3, 6, 9, and 12 hours) at 385°, 400°, and 415° C. Sixty percent of the oxygen was removed in the first 3-hour period; the remaining 40 percent was eliminated with much greater difficulty. These results indicate that at least two types of oxygen linkage are present in coal. Nitrogen removal was slow and approximately constant. Sulphur removal was also slow and occurred to the greatest extent in the first 3 hours.

In connection with this work, a procedure was developed[108] for determining the sulphide, sulphate, pyritic, and organic forms of sulphur in the insoluble residues from hydrogenated coal. The analytical data permit the trend of changes in the relative proportions of forms of sulphur to be followed with increased time of hydrogenation.

Tentative conclusions from the small-bomb experiments are that primary liquefaction, especially in the early stages, is characterized by the elimin tion of coal oxygen, principally as water, and by a decrease in molecular weight of the coal substance, which, after liquefaction, is recovered as a colloidal solution in the vehicle. Although elimination of oxygen and lowering of molecular weight usually occur simultaneously, they appear to be largely independent.

Activation energies of 55 and 32 kg-cal. calculated for the fast and sl oxygen removal, respectively, indicate that the fast reaction is probably a homogeneous liquid-phase hydrogenation reaction of a noncatalytic nature, whereas the slow reaction is probably a heterogeneous hydrogenation reactio involving contact with a surface loaded with activatedly adsorbed hydrogen.

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[106] Hirst, L. L., Hawk, C. O., Golden, P. L., Pinkel, I. I., Boyer, R. L., Schaeffer, J. R., Kallenberger, R. H., Hamilton, H. A., and Storch, H. H., work cited in footnote 104, and Storch, H. H., and Fieldner, A. C work cited in footnote 105, p. 36.

[107] Fisher, C. H., and Eisner, Abner, Primary Liquefaction by Destructive Hydrogenation of the Oxygen, Nitrogen, and Sulphur Linkages: Ind. an Eng. Chem., vol. 29, 1937, pp. 1371-1376.

[108] Abernethy, R. F., Cooper, H. M., and Tarpley, E. C., work cited in footnote 8, p. 6.

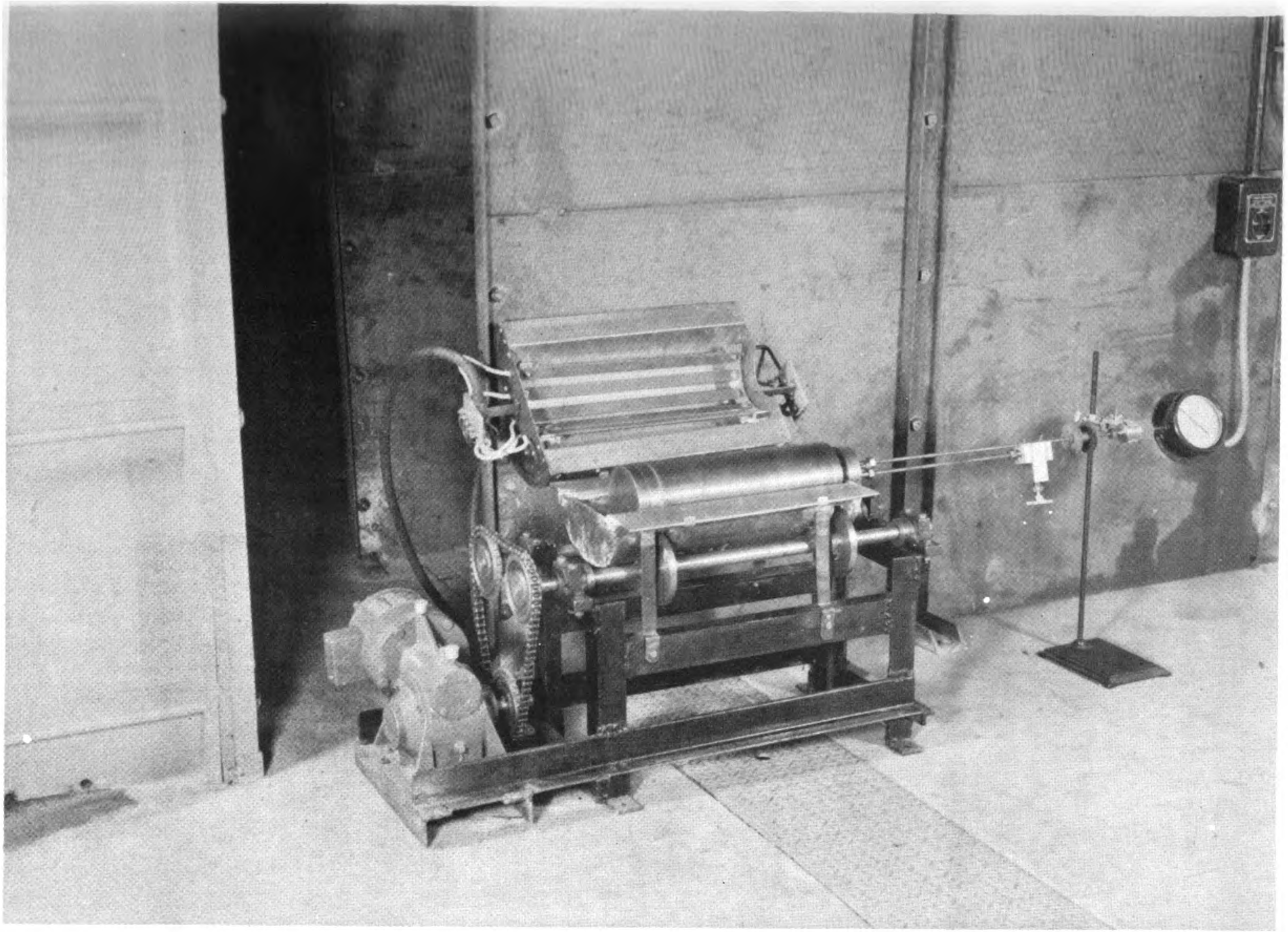

Figure 23.- Apparatus used in small bomb hydrogenation tests.

Further data have been obtained recently on the rate of primary liquefaction of Bruceton coal at various temperatures from 310° to 445° C. These data are given in table 4, with some data from earlier work.[109] An inspection of this table shows that the temperature coefficient of the primary liquefaction (yield of gas plus benzene soluble) varies with the temperature, becoming negative after about 440° C. for 6 hours. If one considers only the yield of benzene-soluble material, the temperature coefficient becomes negative at about 425° C. for 3 and 6 hours contact time and at about 410° C. for 9, 12, and 15 hours. The optimum temperature for the primary liquefaction of Bruceton coal is therefore about 425° C. for contact times less than 6 hours. It is interesting to note that this temperature is 15° C. lower than the optimum found in the experimental plant for continuous hydrogenation. The difference between these observations may be due to the differences in pressure of hydrogen in the two instances, that for the small bomb tests being 500 to 700 pounds lower than that for the experimental plant. The temperature coefficient for the gas yields remains positive at all temperatures.

The maximum temperature coefficient for the yield of benzene-soluble material of table 4 is 1.8 for the 370° to 385° C. interval for 3 hours contact time. This corresponds to an activation energy of 33 kg-cal. It may be significant that this value is almost identical with that obtained for the rate of removal of the last 40 percent of oxygen from the coal under similar conditions. It may be, therefore, that the limiting slow reaction in the liquid-phase hydrogenation of coal is the catalytic hydrogenation of the fragments resulting from the dissociation of the coal substance at an oxygen bond.

TABLE 4. - Data for temperature coefficients of primary liquefaction (B.S. = benzene solubles)[1]

Temperature, °C.	Product	Contact times, hours					
		1	3	6	9	12	15
310	Gas	-	0.9	-	2.1	-	-
310	Gas + B.S.	-	21.0	-	22.0	-	-
340	Gas + B.S.	-	-	-	48.8	-	-
355	Gas	-	1.0	-	2.7	-	-
355	Gas + B.S.	-	33.1	-	81.6	-	-
370	Gas	-	1.7	2.8	4.3	5.3	-
370	Gas + B.S.	-	45.5	71.0	90.0	89.2	-
385	Gas	-	3.5	6.0	7.6	9.5	10.7
385	Gas + B.S.	-	82.2	90.4	91.8	93.8	92.0
400	Gas	2.8	5.5	7.5	9.9	12.3	14.0
400	Gas + B.S.	72.8	90.3	93.0	94.5	95.1	93.1
415	Gas	-	6.9	11.4	15.7	17.9	20.0
415	Gas + B.S.	-	91.7	94.3	95.0	94.6	93.3
430	Gas	-	8.6	13.6	-	-	-
430	Gas + B.S.	-	91.9	92.6	-	-	-
445	Gas	-	18.6	-	-	-	-
445	Gas + B.S.	-	84.0	-	-	-	-

[1] Average pressure was 2,700 pounds in these tests.

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[109] See footnote 109, p. 42.

Hydrogenation of banded constituents. - A series of small-bomb experiments was made out to determine the relative ease of hydrogenation of the various banded constituents of bituminous coals of different ranks and types. The purity of these bands was first determined by microscopic examination of thin sections. Of the seven fusains thus far hydrogenated, appreciable liquefaction was effected in all instances; two samples were liquified to the extent of about 25 percent.[110]

Similar studies on opaque attritus material showed yields between 40 and 85 percent and on translucent attritus and anthraxylon yields up to virtually 100 percent. In all cases these yields can be predicted approximately from the ordinary proximate and ultimate analyses combined with the petrographic analyses of the coal band. The relation between volatile matter and hydrogen-carbon ratio of coal and its banded constituents and its usefulness in predicting hydrogenation yields have been expressed in curves approximated by straight lines. Depending on the units used in the coordinates, different yet fairly definite groupings of the banded constituents may be obtained.[111]

Review of Recent Hydrogenation Work

A critical review was published[112] presenting a discussion of the relative importance of rank of coal, nature of vehicle, type of catalyst, agitation, temperature, and pressure in coal-hydrogenation processes. A second review on contact catalysis in the hydrogenation of coal, coal tar, and oil has been prepared.[113] A third review was presented at a lecture at the University of Maryland on April 26, 1938.[114]

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[110] Fisher, C. H., Sprunk, G. C., Eisner, A., Clarke, L., and Storch, H. H., work cited in footnote 23.

[111] Fisher, C. H., Relation Between Volatile Matter and Hydrogen-Carbon Ratio of Coal and Its Banded Constituents: Ind. and Eng. Chem., anal. ed., vol. 30, 1938, pp. 374-378.

[112] Storch, H. H., Coal Hydrogenation: Ind. and Eng. Chem., vol. 29, 1937, pp. 1367-1371 (correction, vol. 30, 1938, p. 296).

[113] Storch, H. H., Contact Catalysis in the Hydrogenation of Coal, Coal Tar, and Oil. (For publication in a report of The Committee on Contact Catalysis for the National Research Council.)

[114] Storch, H. H., Review on Hydrogenation: Lecture at University of Maryland, April 26, 1938.

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